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Solid modeling for rotary wing design at NPS with AutoCAD R13

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SOLID MODELING FOR ROTARY WING DESIGN

AT NPS WITH AUTOCAD R13

by

Jeffrey S. Lincoln
December, 1997

Thesis Advisor:	E. Roberts Wood
Second Reader:	Conrad F. Newberry

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This thesis is intended to be a reference for solid modeling and Computer Aided Design (CAD) tailored specifically for the Naval Postgraduate School's capstone helicopter design course, AA 4306. The goal is to present the use of AutoCAD R13 software as a central design tool throughout the conceptual design phase of the American Helicopter Society (AHS) Graduate Design Competition project. The specifics of AutoCAD that are essential to performing the design project are explored through examples of model construction and lessons learned from the 1997 VIPER design effort. The usage of solid modeling as a design tool for design team integration is investigated. It is intended for this work to allow future classes to acquire sufficient proficiency with Computer Aided Design and solid modeling. Maximizing the practical usage of CAD techniques in a single quarter will provide an improved learning experience in a more realistic design environment.

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SOLID MODELING FOR ROTARY WING DESIGN AT NPS WITH AUTOCAD R13

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

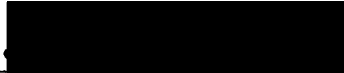## NAVAL POSTGRADUATE SCHOOL
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This thesis is intended to be a reference for solid modeling and Computer Aided Design (CAD) tailored specifically for the Naval Postgraduate School's capstone helicopter design course, AA 4306. The goal is to present the use of AutoCAD R13 software as a central design tool throughout the conceptual design phase of the American Helicopter Society (AHS) Graduate Design Competition project. The specifics of AutoCAD that are essential to performing the design project are explored through examples of model construction and lessons learned from the 1997 VIPER design effort. The usage of solid modeling as a design tool for design team integration is investigated. It is intended for this work to allow future classes to acquire sufficient proficiency with Computer Aided Design and solid modeling. Maximizing the practical usage of CAD techniques in a single quarter will provide an improved learning experience in a more realistic design environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

AA 3272	Introduction to Systems Engineering Course
AA 4306	Graduate Helicopter Design Course
AHS	American Helicopter Society
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BMP	Bitmap file format
CAD	Computer Aided Design
C.G.	Center of Gravity
DWF	Drawing Web File Format
DWG	Drawing Geometry File Format
DXF	Drawing Interchange File Format
EM	Electro-Magnetic
GUI	Graphical User Interface
IGES	Initial Graphic Exchange Specification
JANRAD	Joint Army/Navy Rotorcraft Analysis and Design Software
MB	Mega-Bytes
MHz	Mega-Hertz
MMX	Intel Multi-Media Technology
NACA	National Advisory Committee for Aeronautics
NPS	Naval Postgraduate School
NURBS	Non-Uniform Rational B-Spline
PC	Personal Computer
R13	Revision 13 of AutoCAD Software
RAM	Random Access Memory
RF	Radio Frequency
RFP	Request for Proposal
SAR	Search and Rescue

SAT	ASCII Drawing File Format
SDRC	Structural Dynamic Research Corporation
SURFTAB	Surface Tabulation
UAV	Unmanned Aerial Vehicle
UPOTG	Unsteady Potential Code with GUI
VTOL	Vertical Take-Off and Land
WMF	Windows Meta-File format

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I. INTRODUCTION

A. BACKGROUND

1. Purposes and Goals

This thesis presents the specific tools and methodology needed to more fully

utilize solid modeling as a design strategy for integrating Computer Aided Design (CAD)

in the Naval Postgraduate School capstone helicopter design course. Specifically, the use

of AutoCAD will be presented for this purpose; however, the same concept may be

pursued with other CAD products of similar sophistication. The goal is to assist future

students to more rapidly acquire the level of proficiency with AutoCAD needed to fully

incorporate solid modeling from the beginning of the conceptual design phase. This will

enable the design class to focus greater attention on the design processes and to devote

less time learning CAD skills.

It is desired that this guide be available to students at least one quarter prior to the

beginning of the Helicopter Design course (AA 4306) or during the Introduction to

Systems Engineering course (AA 3272). Students may review the concepts of solid

modeling and follow the practice exercise to develop proficiency with the software early

in the helicopter track. Ideally, at least one student within the prospective design group

will acquire a high enough level of understanding to pursue a specific modeling strategy

for the assigned design project.

In the years during which CAD software has developed, debate has ensued over

the level of computer use to be incorporated in a conceptual design course. Some

institutions side with the need to instruct from a traditional approach, using mostly

analytical and graphical methods to gain an appreciation for the difficulty of the design process. However, most engineering programs now heed the desire from industry to educate with tools presently used in the workplace. In a graduate aeronautical engineering program such as at NPS, the majority of students have design experience from a basic undergraduate engineering program. The greatest educational benefit for these students will come from a realistic environment closely resembling the methods and organization of a modern design team in industry. A major difficulty of achieving this in one academic quarter is the time required to become familiar and proficient with available CAD software to benefit from its use. Despite the wide array of CAD tools available at NPS, very few students are able to use them in design courses.

2.   Helicopter Design at NPS

AA 4306 is the helicopter track capstone design course within NPS's Aeronautical Engineering Department. It is the final quarter of a three-quarter sub-curriculum in helicopter engineering principles. The coursework of AA 4306 involves a group design project based upon entry into the annual American Helicopter Society (AHS) Graduate Design Competition Request For Proposal (RFP). The course instruction pursues a response to the RFP from conceptual design through to a presentation level design of moderate detail and rigorous analysis. With this Annual participation, the course has evolved from basic helicopter design focussed solely on a single main rotor/tail rotor design project [Ref. 1] to a more dynamic and challenging program focussed on leading edge technology and current design issues in the vertical flight industry. Appendix A presents a more detailed history of NPS's participation in the AHS competition. Along with this evolution has come the increased challenges of a

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wider base of knowledge and skills required of the students to deal with the design of

hybrid vehicles such as tiltrotors, rotorcraft UAV's, or compound helicopters. The NPS

students who undertake this sub-curriculum are uniquely prepared to meet these

challenges based on their extensive operational backgrounds flying various military

helicopters from all of the armed forces. To support the design course, the department

has assembled an extensive collection of CAD and simulation tools some of which are

detailed in Appendix C. Much of this software is the product of student thesis work and

faculty research.

3. Motivations

The impetus for pursuing the subject of this thesis arose from lessons learned

from the 1997 design team response to the AHS Request For Proposal, the VIPER,

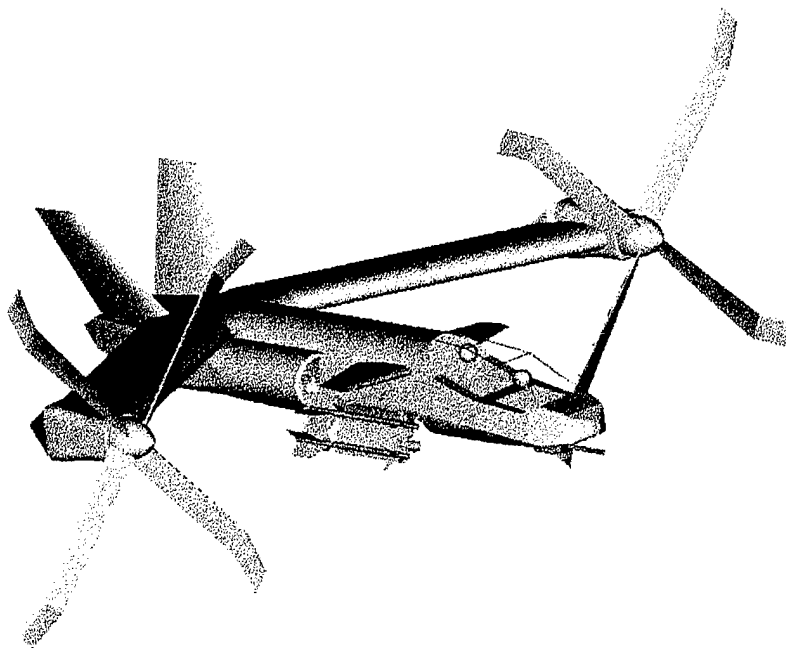Figure 1.1, Advanced Tactical Tiltrotor, as well as the author's personal experience in

Figure 1.1 "VIPER" Advanced Tactical Tiltrotor AutoCAD Solid Model

learning AutoCAD for use in this project. It is the author' opinion that the educational experience of the course and the resulting quality of the design project will greatly benefit from the use of this thesis.

The 1997 design team began the VIPER project having no experience with CAD drafting or the department's computer analysis software. Since the curriculum has no specific course of instruction for these tools, it was incumbent on team members to individually learn their use through self-study of available manuals and trial and error in their use. For some complex CAD tools such as AutoCAD, the amount of effort required to acquire even a basic proficiency is enormous. This greatly reduced the time available to focus on the design process. However, the benefits that may be derived necessitate its use and can reduce time required in other areas of analysis. Unfortunately, this observation and the skill level required to exploit the benefits occurred too late in the process. It was observed that the use of a solid modeling tool such as AutoCAD throughout the preliminary design phase could be used to integrate and facilitate other CAD tools such as finite element, performance, and dynamics modelers. This integration can reduce duplicity of effort among team members and between stages of design. Solid modeling can also provide a complete design database and improve the three dimensional visualization of the project throughout the design process.

The use of Computer Aided Design tools in product development is the standard in industry today. The rapid growth of the computer drafting, modeling, and simulation software market has produced easy use, low cost design technology, which has made mechanical drafting obsolete. The aerospace industry, particularly BOEING, has

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championed the ability to use fully integrated computer modeling and simulation from conceptual design through to the end of product lifecycle support. Industry in general has recognized this as a means to reduce the cost and time of product development.

AutoCAD has traditionally been used as a drafting tool in the end game of the design process in the NPS helicopter design project. However, using it as an integrating tool in this design process will more closely mirror the process used in industry. The end product will be a complete computer model and database ready for use in higher level analysis.

B.   METHODOLOGY

This thesis focuses on presenting those AutoCAD skills and solid modeling strategies found to be most applicable to the helicopter design course. This requires students to learn a subset of skills and commands. This, in turn, will enable the helicopter design students to rapidly acquire the proficiency needed at the beginning of the design course, while recognizing that the majority of a student's knowledge and ability will still result from individual experimentation and practice with software.

Chapter II gives the student a fast demonstration of an AutoCAD aerospace application in a manner, which does not require prior CAD experience. Its purpose is to motivate the reader to invest the time to explore later chapters. These chapters focus on the solid modeling concept (Chapter III), various techniques for building a rotary wing CAD model (Chapter IV), commands and procedures for obtaining quality output products (Chapter V), and lessons learned from the 1997 project (Chapter VI).

II.   FAST AUTOCAD CONFIDENCE EXERCISE

A. INTRODUCTION

This chapter will permit the reader to quickly gain a degree of confidence and motivation to further explore this topic. The exercise will require about two hours to complete. It is assumed that the user is familiar with the Windows environment and the use of toolbars and icons as an interface.

In this exercise, a simplified shell of a hypothetical tiltrotor aircraft (in the airplane mode) will be constructed as shown in Figure 2.1. A number of basic commands will be presented. The procedure used will present the array of commands and
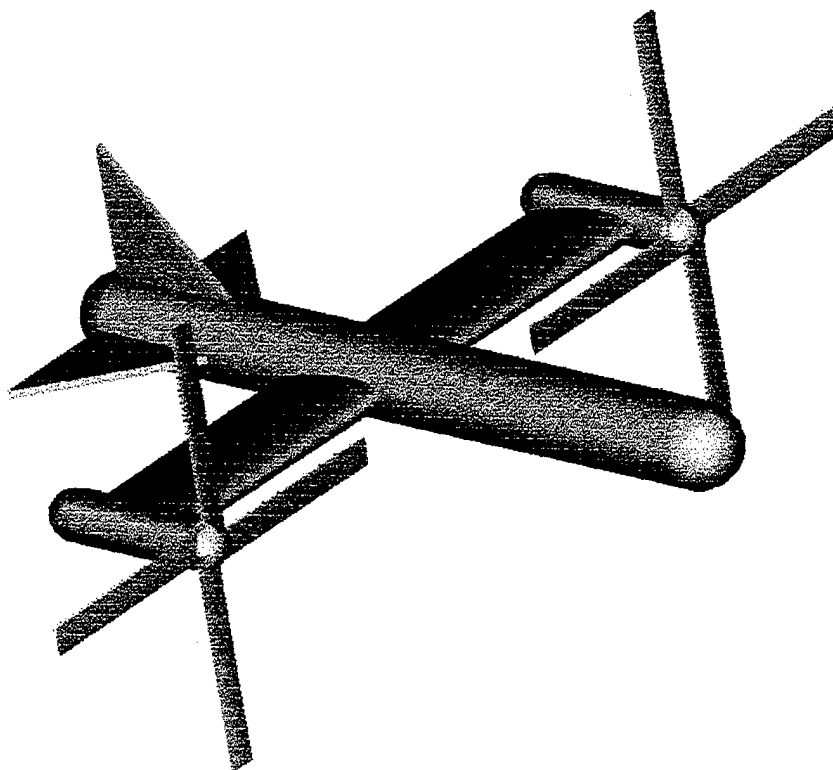
Figure 2.1 Rendered Exercise Tilitrotor Model

construction methods most useful in rotary wing solid modeling in one example exercise. The knowledge acquired from this exercise will facilitate understanding of the chapters that discuss the concept of solid modeling and more advanced modeling strategies for the NPS helicopter design project. It is strongly recommended that the reader complete this exercise before continuing on to the remaining chapters.

AutoCAD operates in a Windows environment when installed on a PC with a Windows operating system. It uses a pull-down menu, toolbars, and icons for use with a mouse as well as a command line prompt for entering via keyboard. There is a central workspace window, called a viewport, surrounded on the borders by the menu and toolbars. All commands may be invoked either with icons or the command prompt line. It is crucial that the user observe that within toolbars, icons are stacked and must be pulled down for access. The icons that are stacked have small triangles in the lower right corner.

The workspace window uses Cartesian coordinates (X,Y,Z). Planar objects are constructed in X-Y planes at various user selected 'elevations' (Z coordinate). It will be necessary for the user to pan and zoom in/out in the workspace window to adequately view the model. This is accomplished with the sliding border bars and the zoom in/out icons. The ZOOM icons are represented with magnifying glass symbols.

B.   EXERCISE INSTRUCTIONS

- Call up AutoCAD with the Windows icon (Windows 3.2) or from the start menu (Windows '95)

- type "surftab1", type "15", and hit enter key

- type "surftab2", type "15", and hit enter key

- go to "tools" menu, select "toolbars" submenu, pull out the "views" toolbar, place it in a screen margin area, and click on the icon "top view" (the icon names will appear as the mouse arrow rests on top)

We will first create an airfoil cross section with coordinates for a 7-ft. chord NACA 0021 airfoil

- type "elev" and hit enter key

- type "20" and hit enter key

- type "0" for the thickness and hit enter key

- pull down the "tools" menu, select the "toolbars" submenu, pull out the "draw" toolbar, place it in a screen margin, and click on the "polyline" icon

- at the command prompt type in the following XY coordinate points, striking the enter key between each point: (read left to right)

7.00,0.00	6.84,-0.05	6.34,-0.17	5.57,-0.35	4.59,-0.54	3.51,-0.69
2.42,-0.73	1.44,-0.71	0.67,-0.69	0.38,-0.57	0.17,-0.39	0.04,-0.19
0.00,0.00	0.04,0.17	0.38,0.57	0.67,0.69	1.44,0.71	2.42,0.73
3.51,0.71	4.59,0.54	5.57,0.35	6.34,0.17	6.84,0.05	7.00,0.00

(If you incorrectly enter a point, you may use the undo arrow and continue to enter points)

- hit enter key

An airfoil should appear as in Figure 2.2

- on the "draw" toolbar, click on the "line" icon
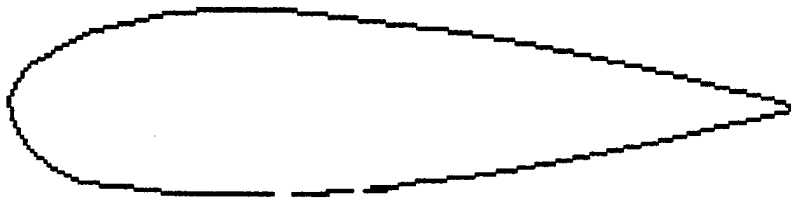
Figure 2.2 NACA 0021 Airfoil

- type the coordinate "7.0,0,20", hit enter key, type coordinate "7.00,0,-20", and hit enter key

- on "view" toolbar, click on the "NW isometric view" icon

- from the "toolbars" submenu, pull out the "surfaces" toolbar, and click on the "extruded surface" icon

- click on the airfoil with mouse

- click on the line with mouse

You should now have a wing section as shown in Figure 2.3. Now we'll create a fuselage section.

Figure 2.3 Extruded Wing Section

- pull out the "solids" toolbars and select the cylinder icon with the tag "center"

- type coordinate "-20,0,0", hit enter key, type "2.5" for the radius, hit enter key, type

  "c", hit enter key, type coordinate "20,0,0", and hit enter key

A cylinder should appear perpendicular to the wing section as in Figure 2.4
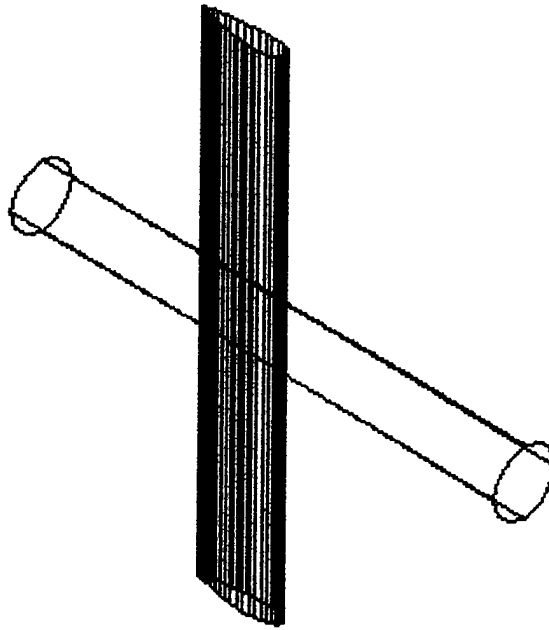
Figure 2.4 Fuselage and Wing Sections

- on the "surface" toolbar, click on the "dome" icon, type the coordinate "-20,0,0", hit

  enter key, type "2.5" for the radius, hit enter key, and hit enter key again

  The fuselage nose cone will appear as in Figure 2.5

- type command "rotate3d", hit enter key

- click on the dome with the mouse, hit enter key, type "y", type coordinate "-20,0,0",

  hit enter key, type "-90" for rotation angle, hit enter key
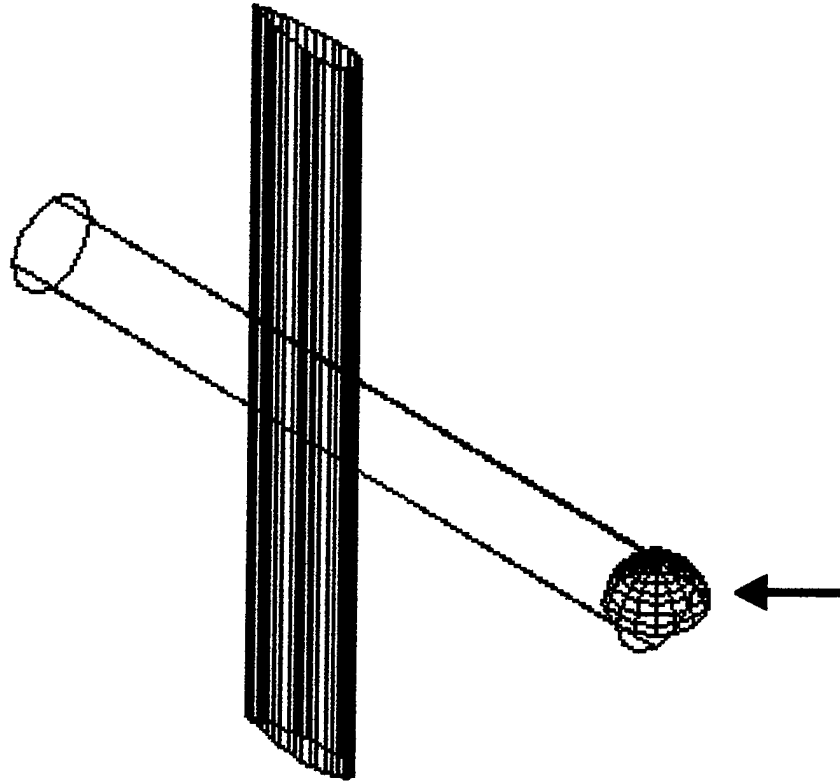
Figure 2.5 Nose Cone

The nose cone is now in its proper orientation. Next we will create a rotor system by building a single blade and making copies of it.

- on the "draw" toolbar, click on the "polyline" icon and enter the following coordinates as before: (read left to right)

-2.50,-1.31	-2.51,-1.24	-2.54,-1.02	-2.57,-0.71	-2.60,-0.35	-2.60,0.00
-2.60,0.15	-2.58,0.27	-2.56,0.36	-2.53,0.42	-2.50,0.44	-2.47,0.42
-2.44,0.36	-2.42,0.27	-2.40,0.15	-2.40,0.00	-2.40,-0.35	-2.43,-0.71
-2.46,-1.02	-2.49,-1.24	-2.50,-1.31			

- hit enter key and then hit enter key again

As with the wing section, this is an airfoil section that is one end of the rotor blade. See Figure 2.6 (you will need to zoom into the wing tip area to get a better view)

- on the "draw" toolbar, click on the "line" icon, type the coordinate "-2.5, -1.31,20", hit enter key, type coordinate "-2.5,-1.31,7", hit enter key, and hit enter key again
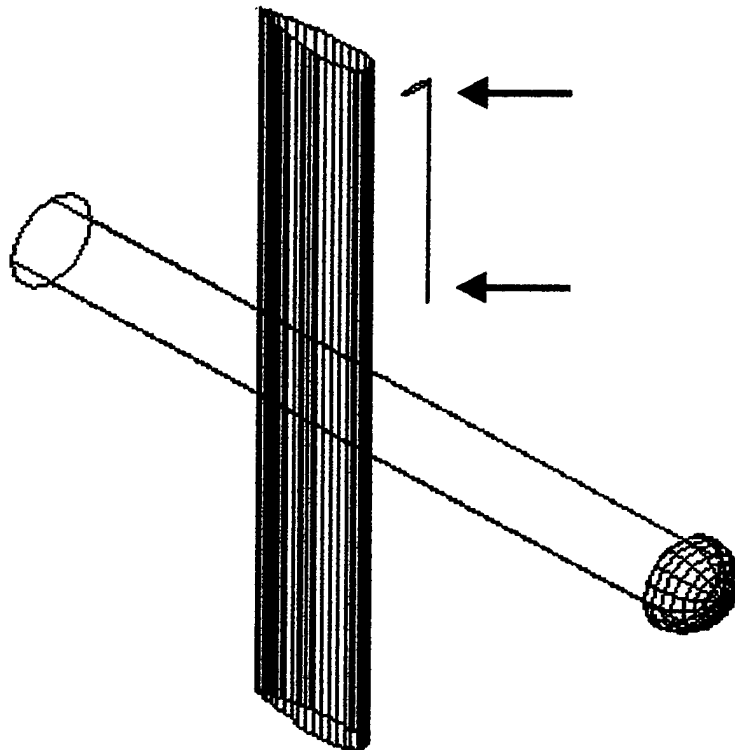
Figure 2.6 Blade Airfoil

- on the "solids" tool bar, click on the "extrude" icon

- click on the rotor blade airfoil with mouse, hit enter key, type "p", hit enter key, and click on the new line, and hit enter key (see Figure 2.6)

The extruded solid rotor blade should appear as in Figure 2.7.
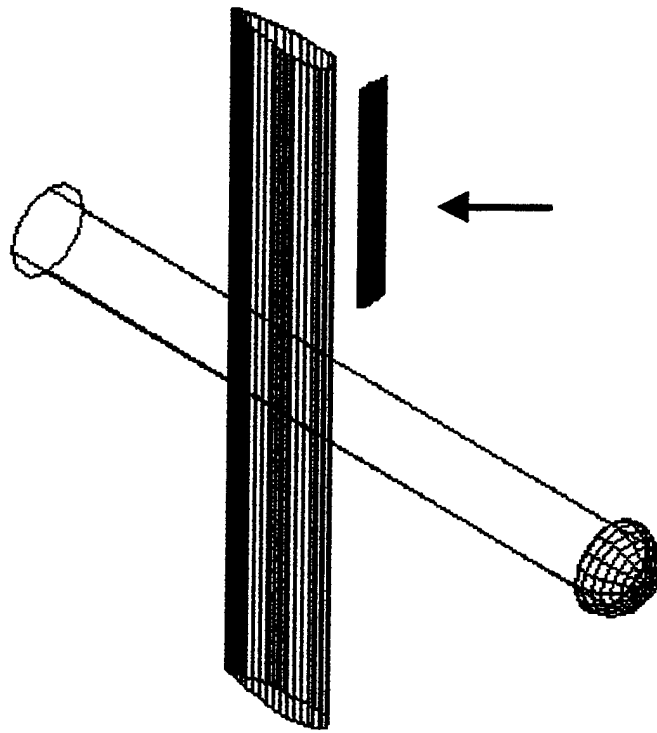
Figure 2.7 Rotor Blade Extrusion

The remainder of the proprotor will be created by the following shortcut method:

- pull out the "modify" toolbar and click on the "3D polar array" icon

- click on rotor blade with the mouse and hit enter key

- type "4", hit enter key, type "360", hit enter key, type "y" , hit enter key, type

    coordinate "-2.5,0,20", hit enter key, type coordinate "0,0,20" and hit enter key

You should now have four proprotor blades on the left side of the model as shown in

Figure 2.8
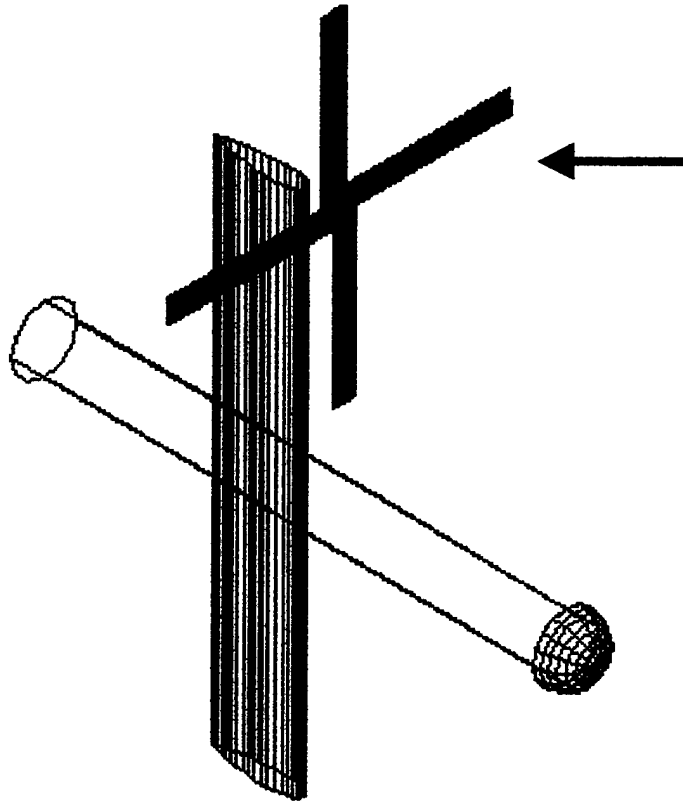
Figure 2.8 Left Proprotor System

We will now build a cylinder for a wing tip nacelle by revolving a rectangle 360 degrees in space.

-   on the "draw" toolbar, click on the "rectangle" icon

-   type coordinate "-2,0,20", hit enter key, type coordinate "7,-1.5,20", and hit enter key

-   on the "solid" toolbar, click on the "revolve" icon

-   click on the rectangle with the mouse and hit the enter key

-   type coordinate "-2,0,20", hit enter key, type coordinate "0,0,20", hit enter key, and hit enter key again

A cylinder should have appeared at the wing tip as in Figure 2.9.

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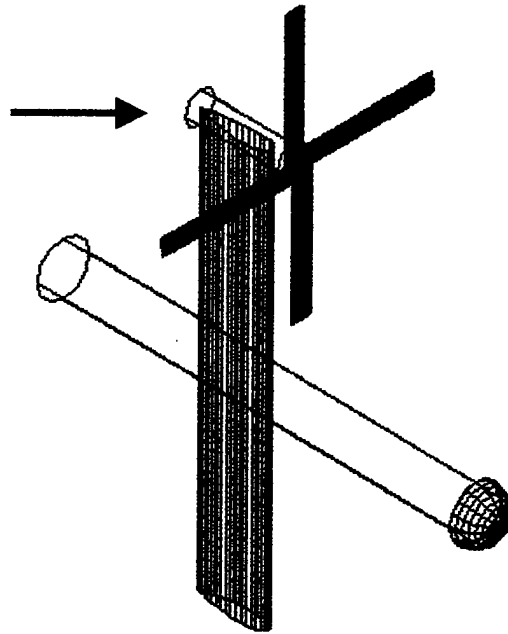
Figure 2.9 Wing Tip Nacelle

Now we will make a spinner for the center of the proprotor

- on the surface toolbar, click on the "dome" icon

- type coordinate "-2,0,20", hit enter key, type "1.5", hit enter key, type "8", hit enter key, type "5", and hit enter key

Once again we will need to rotate the dome into position

- type "rotate3D" and hit enter key

- click on the dome with the mouse and hit enter key

- type "y", hit enter key, type coordinate "-2,0,20", hit enter key, type "-90", and hit enter key

- on "view" toolbar, click on "back"

The spinner should now be in place as shown in Figure 2.10.
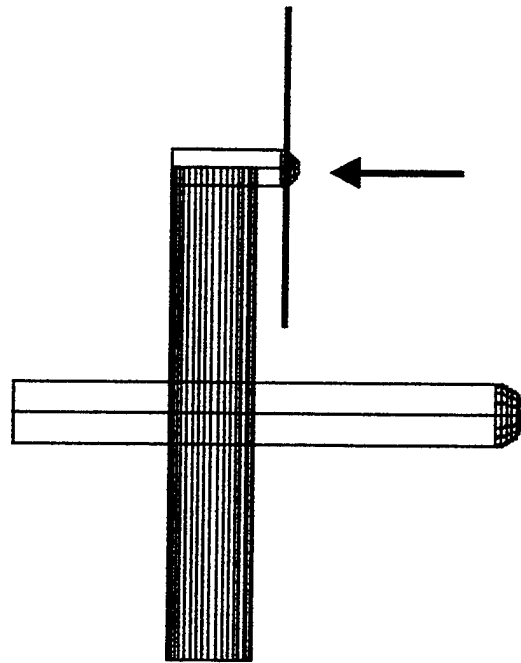
Figure 2.10 Nacelle Spinner

We will now use another shortcut to place a tail cone on the nacelle.

- type "mirror3d" and hit enter key

- click on the spinner with the mouse and hit enter key

- type "yz", hit enter key, type coordinate "2.5,0,0", hit enter key, and hit enter key
  again

  A dome should appear on the back of the nacelle. We will now use the same

  procedure to place a tail cone on the fuselage as shown in Figure 2.11

- type "mirror3d", hit enter key, click on the fuselage's nose cone with the mouse, and

  hit enter key

- type "yz", hit enter key, type coordinate "0,0,0", hit enter key, and hit enter key again

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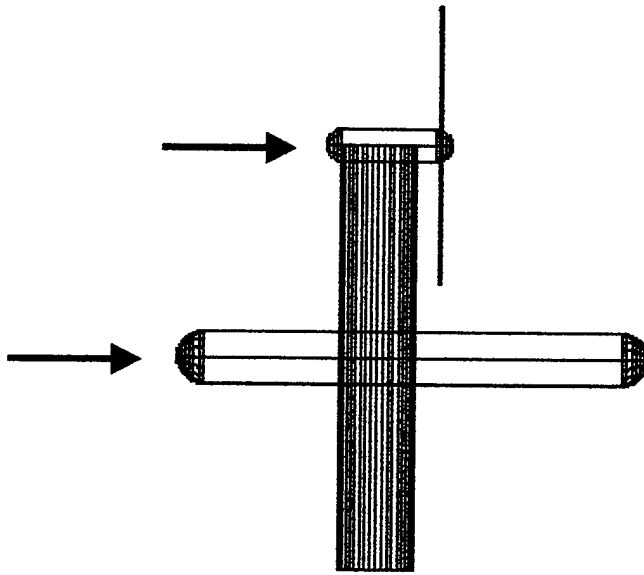
Figure 2.11 Fuselage and Nacelle Tail Cones

Now we will create the tiltrotor's other nacelle and proprotor system using the "mirror3d" command.

- on the "view" toolbar, click on "NW isometric view"

- type "mirror3d" and hit enter key

- use mouse to click on the spinner, nacelle, nacelle tail cone, and all four rotor blades. Hit enter key

- type "xy", hit enter key, type coordinate "0,0,0", hit enter key, and hit enter key again

The model should appear as in Figure 2.12.

We will finish this tiltrotor model by creating an empennage

- type "elev", hit enter key, type "0", hit enter key, hit enter key again

- on the "surface" toolbar, select the wedge icon with the tag "corner"
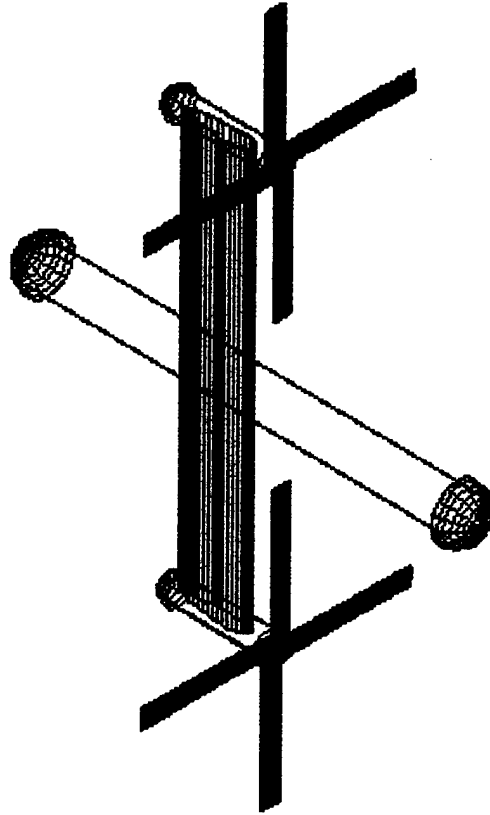
Figure 2.12 Both Proprotors

- type coordinate "20,2,0", hit enter key, type coordinate "12,2.5,0" , hit enter key, type "8", and hit enter key.

- On the "view" toolbar, click on "SE isometric view"

- type "rotate3d" and hit enter key

- click on the wedge you have just created and hit enter key (see Figure 2.13)

- type "x", hit enter key, type coordinate "0,2.25,0", hit enter key, type "-90", and hit enter key
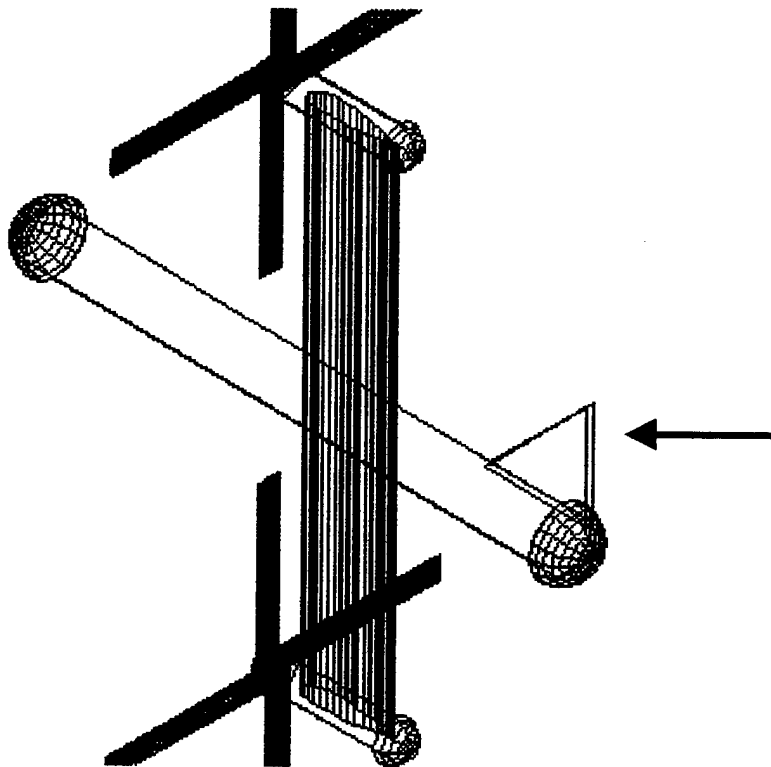
Figure 2.13 Vertical Stabilizer Fin

The model should appear as in Figure 2.14

- type "3Darray" and hit enter key

- click on the vertical stabilizer with the mouse and hit enter key

- type "p", hit enter key, type 4, hit enter key, type "360", hit enter key, and hit enter key again

- type coordinate "20,0,0", hit enter key, type coordinate "0,0,0", and hit enter key

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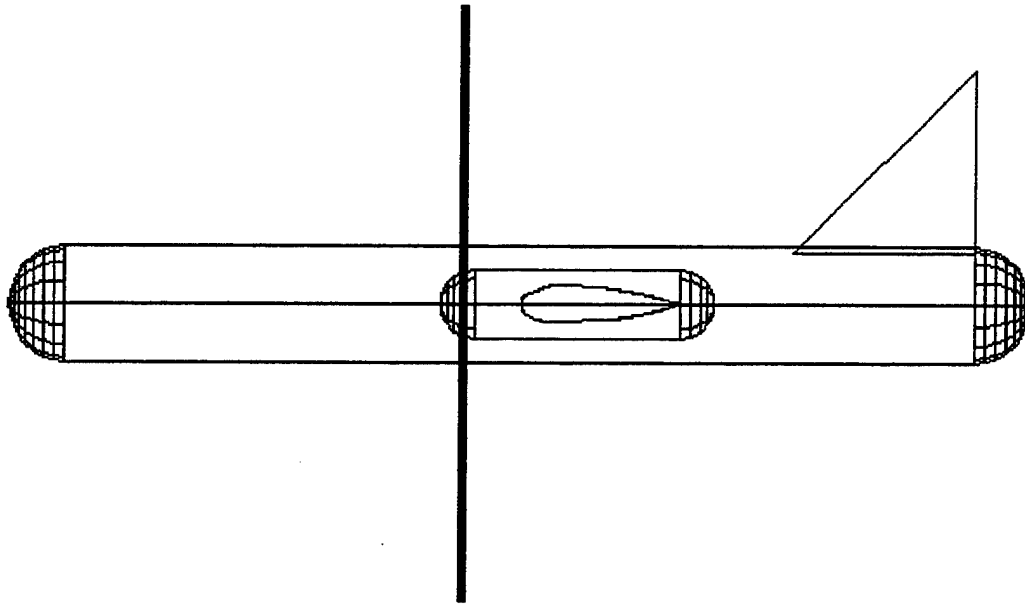
Figure 2.14 Vertical Stabilizer Fin in Upright Position

-   click on the bottom fin on the aircraft tail with the mouse and "cut" it with the
    scissors icon or using the edit menu

    The model is now complete. You may view it from various angles using the icons on

    the "view" toolbar and the "zoom" icons. (See Figure 2.15)

-   Pick one view angle from the VIEW and type "render" then hit enter key. When the

    GUI window appears, hit enter key again. Your model may appear as shown back in

    Figure 2.1
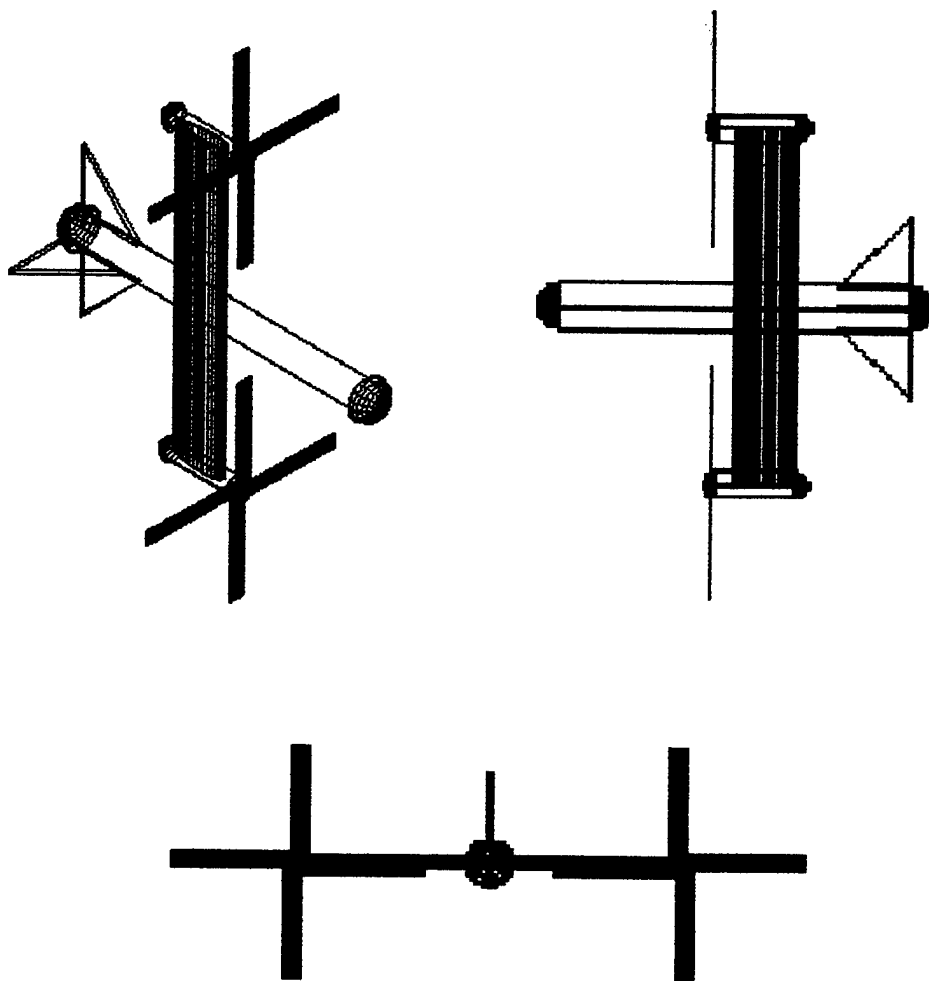
Figure 2.15 Tiltrotor Model from Various Aspects

C.   COMMENTS

The model created in this exercise serves to illustrate the ease and quickness in which a few basic commands and operations can be employed for the specific task of modeling a rotary wing design. Hopefully, this drill has the effect of reducing any intimidation and confusion you have in learning what first appears to be a complex process.

III.   SOLID MODELING

A.   CONCEPT OF SOLID MODELING

Solid modeling is the computerized representation of physical objects or phenomena. It creates a complete three-dimensional geometrical visualization and database of a design's actual form. Incorporating solid modeling into product development integrates design, analysis, and manufacturing process teams. These tasks can then approach parallel efforts rather than serial [Ref. 2]. The CAD solid model becomes a shared database for parallel efforts in structural analysis, performance, weight & balance etc. Solid modeling then becomes more than simply a drafting and visualization tool, it is the integrating methodology for computer design, analysis, simulation, and manufacturing.

The finished solid model provides a complete geometrical and material properties database for future applications. Large commercial manufacturers, especially those in the transportation industry like Chrysler, Ford, and BOEING have capitalized on this as a means to drastically reduce development time and life cycle costs while in the design phase. Other fields and industry also employ solid modeling. Medical research uses solid modeling with virtual reality for visualization and training. RF engineering firms use it to describe EM fields and antenna modeling.

Although termed solid modeling, the construction typically occurs with both solid objects and surfaces. Solid object construction is primarily limited to basic geometrical shapes that can be cut. Surfaces have a greater capability to model complex shapes due to their numerical algorithms, but they can represent the internal characteristics of an

object. The latest tool for surface objects to define complex shapes is the Non-Uniform Rational B-Spline (NURBS). The ability to fully integrate surface and solid mathematical representations hasn't been developed yet [Ref. 3]. However, the latest AutoCAD R14 release has the capability to slice solids with complex geometry defined by NURBS [Ref. 4]. This would be very helpful in creating complex aerospace shapes.

Solid Modeling for the helicopter design course at NPS should begin at the transition from conceptual to preliminary design phases. With previously developed CAD skills, the initial design concept needs to be quickly modeled. This enables visualization and understanding of the initial design as a starting point for the team. The model data is available to all participants as they break up into areas of specialization such as powertrain, performance, structures, avionics, etc. Once this base design exists, modifications require far less effort and time. Changes can be made to the model with operations such as scaling, deletion, moving, and mirroring. These are presented in the next chapter.

Each team member's individual design efforts are continuously reincorporated into the model to analyze the interaction of the systems design on the entire model. For example, the frames designed with NASTRAN could be imported back into the model. With each weekly progress meeting, the team can view the progress of the entire design. The data of the current design is then extracted by participants or translated (via IGES) to other CAD systems as the next iteration in the design begins. This iterative process ends when review of the model reveals that all design parameters are met with no conflicts between systems.

The completed model is fully developed at the last iteration. The model now represents a wealth of data and potential for automation. Descriptive draftings, renderings, dimensioned views, and properties can be quickly extracted from the model. Each team member has these utilities available in preparing the final proposal for his area of specialization. For example, rotor blade cross sections and planform views can be produced from the model. The entire fuel system could be rendered separately in its location.

At the end of the design phase, the solid model is available for further analysis. It would not be necessary to research or recreate the design data. The progress history of the project is preserved with the model data files that exist from all design iterations. It would all exist electronically on a ZIP sized diskette. Downstream uses could include thesis research for further aerodynamic or structural investigations. It may also be easily transferred to another agency such as the Army Aeroflightdynamics Directorate at NASA-Ames or other government agency. Ideally, it will be a ready resource for a winning NPS design team to prepare their presentation to the AHS.

At this point in industrial applications, the solid model would proceed to rapid product prototyping for manufacturing and reliability analysis. Ultimately, the CAD solid model of a manufactured product can exist for the life of the product. It would be used for design modifications, development of technical publications, or in aviation applications for mishap simulation for crashes. The underlying concept is that the solid model database begins at preliminary design and is maintained as a productive and useful tool for the entire product life. While the initial time investment in its creation is significant, the payoff in effort comes in the application.

B.   UTILITIES OF THE SOLID MODEL

The database of the solid model has potential to facilitate other applications in analysis of the design. With the Initial Graphics Exchange Specification Software (IGES) translator software capability, the design constructed in AutoCAD can be exported to other CAD programs such as PATRAN or IDEAS for structural analysis. Its geometry can be used for preparing the model for an aerodynamics panel code with the NASA-AMES GRIDGEN program.

The IGES translator converts the model's geometry from one CAD systems data format to another. It is an ASCII data format that is neutral to the many CAD formats. It was developed by CAD venders and the US Government for transfer of product data in a vender neutral format. An example of the VIPER's geometry translated into PATRAN is shown in Figure 3.1. It can be observed that not all of the AutoCAD entities were preserved as is discussed more in Chapter V. PATRAN is the CAD tool used with NASTRAN as the primary structural analysis software at NPS. IDEAS modeling and simulation software also perform finite element analysis. The translation into IDEAS was nearly identical in quality to the PATRAN conversion. The potential times savings in avoiding duplication of effort is important to pursue.

GRIDGEN is a code developed by NASA-AMES to prepare aircraft model geometry for aerodynamic analysis. It is designed to build the meshed panel used in panel codes for computation of pressure distributions. It also has the ability to import IGES data files. This was attempted for the VIPER model with even less success as shown in Figure 3.2. Only the wings, nacelles, and weapons bay geometry survived the

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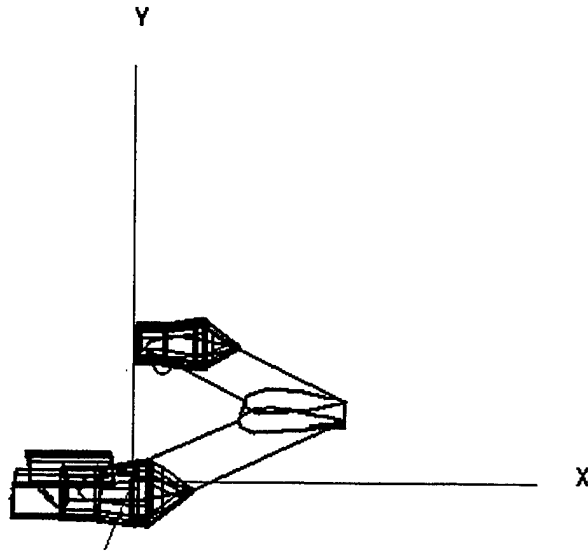
Figure 3.1 GRIDGEN Interpretation of IGES Translated VIPER Model

conversion. In addition to the problem of using an old IGES release. GRIDGEN has

difficulty with large data files such as the VIPER, which approaches 3MB. This was the

case in Figure 3.2. GRIDGEN provided a warning statement that most of the geometry

had to be ignored. A partial solution to this would be to input smaller portions of the
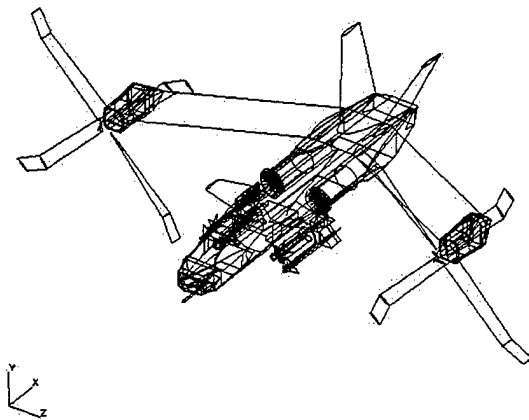
Figure 3.2 PATRAN Interpretation of IGES Translated VIPER Model [Ref. 5]

model with a smaller data size. It is unlikely that a design team would need the ability to carry a design to the level of a panel code analysis, but its is an interesting capability to investigate.

There are many applications for which a solid model of the type created in AA 4306 could be utilized. Survivability simulations are increasingly dependent on computerized simulation with solid models to view locations of systems as damage occurs. The geometrical size and shape of an aircraft are big factors in stealth design. There are many programs that use modeling to analyze an aircraft's radar cross section. The NPS Electrical Engineering department's PATCH program is one such program that is dependent on input surface geometry. The NEC software for computing EM fields is used with surface geometry to evaluate the interaction of surface geometry and material with antenna. All these require the effort of an initial development of a model's geometry and properties.

For the VIPER project the completed solid model was essential for visualization. Many potential flaws were realized in the CAD model that likely would not have been discovered from a paper drawing. Specifically geometry and aircraft real-estate problems were identified. The weapons bay was initially believed to be large enough to carry eight Hellfire missiles. However, when the missiles were placed in the aircraft model, it was found that truly only six fit. Further it was observed by rotating the weapons bay door in the AutoCAD model that with the initial arrangement of the six missiles, the missiles interfered with one another as the bay door opened. Also, the geometry of the transmission drive shafts, which were designed on paper, did not match the swept geometry of the wings. The drive shaft and nacelle gearboxes did not line up with the

proprotors. The design of the landing gear bay was design interactively in the AutoCAD

model since the volume available was critical in the locations the struts needed to be

placed.

IV. MODELING TECHNIQUES FOR AEROSPACE VEHICLES

A. INTRODUCTION

This chapter presents a select group of AutoCAD commands and construction techniques that will allow the NPS helicopter design class (AA 4306) to create a CAD model for design and analysis. Mastering these select tools will develop sufficient modeling skills for the tasks required of the helicopter design team without requiring an inordinate amount of time. Various modeling tools will now be presented with a discussion of the benefits of each.

B. THE AUTOCAD R13 MODELING ENVIRONMENT

AutoCAD is a three-dimensional Computer Aided Design modeling tool with the capability of depicting 3-D graphical files in a viewport window at selected viewing angles. The program is presented in a Windows environment when installed on an IBM type PC. AutoCAD has numerous commands for creating 2-D and 3-D geometric objects, surfaces, and 3-D solids. Tools exist to modify, analyze, and display these objects. All commands may be selected either using the toolbar icons or typed on the command line prompt [Ref. 6].

Model objects are saved in the AutoCAD drawing file format that has the file name extension of .dwg. Drawings may be exported into other file formats such as Metafiles (.wmf), bitmaps (.bmp), drawing exchange files (.dxf), or ASCII (.sat) [Ref. 6]. However, these drawing file formats do not export all of the properties of the CAD solid model. An IGES translation must be accomplished to export an entire model to another CAD system as was discussed in Chapter III.

The AutoCAD workspace is defined in Cartesian coordinates to spatially display the drawing objects. This three-dimensional space is composed of user selected drawing levels or elevations (X-Y planes) of a specified Z coordinate. Unless otherwise designated on the command line with the ELEV command, three-dimensional objects are placed in the current drawing level by default. For example, a line created by selecting two endpoints with the mouse will be placed coplanar with the drawing level. However, if X,Y, and Z coordinates are specified for each endpoint, the line will be placed with the desired orientation.

Objects in the workspace may be viewed from any vantage point in space using the VIEW toolbar. There are 10 preset views that may be selected from the STANDARD toolbar or the VIEW menu [Ref. 6]. A user-defined view may be selected from the VIEW menu with the 3D VIEWPOINT option. The model may also be viewed and rotated in real time using the 3D DYNAMIC VIEW option on the VIEW toolbar. The models relative size to the viewport may be altered with the ZOOM icons on the STANDARD toolbar to assist in viewing detailed parts. Beware of zooming down to too small a scale. This has been observed to cause a crash of the AutoCAD R13 software.

C.   POINTS, LINES AND OTHER ELEMENTARY OBJECTS

Points, lines, and curves are essential as basic objects which are used for building blocks to create more complex solids or surfaces. For example, the rotor blades created in the exercise of Chapter II were constructed from connected lines extruded in a direction and distance defined by another line.

Points may be entered at any location in space by either of two methods. A point may be placed with the POINT icon on the DRAW toolbar by clicking the mouse at a location on the current drawing level. The location of the point may also be designated by its Cartesian coordinate on the command prompt line [Ref. 6].

Lines may be created in the drawing level by using the mouse to designate the endpoints of the line. This will create a line coplanar to the drawing level. Also, the endpoints of the line may be designated on the command prompt line. The line then will be placed at a designated attitude, not necessarily coplanar to the drawing level.

Various types of curves may be constructed using the ARC, POLYLINE, and SPLINE icons on the DRAW toolbar [Ref. 6]. The required data to define a particular curve is prompted on the command line after selecting an icon. In the exercise of Chapter II, the airfoil is created from a polyline. See Figure 2.2.

A closed loop two-dimensional geometry may be created by the POLYGON, CIRCLE, and ELLIPSE icons on the DRAW toolbar [Ref. 6]. The defining parameters of these objects may be entered either by the mouse or the command prompt line. However, for objects that will later be used to create solids or surfaces, it is preferable to enter coordinate and dimensions via the command prompt. This will ensure precision in aligning and joining objects. Additionally, all curves used for extruding objects must be closed loops. The polygon used for the airfoil in Chapter II has common start and end points for this purpose. Points selected with a mouse may not have adequate precision to ensure this.

D.   MODELING WITH SOLID OBJECTS

In AutoCAD, creating a three dimensional model with solid geometric objects requires planning and vision to create a uniquely shaped object from more common shaped objects such as cones, cubes, wedges, spheres, etc [Ref. 6]. These more common solid geometric objects are combined or subtracted to create more complex objects. Various operations can be performed to modify a shape. Intersecting planes may be used to slice or divide the object. Planar, two-dimensional objects may be extruded or revolved to create an irregular solid. The edges where two planes meet may be camfered or filleted using icons on the MODIFY toolbar. Therefore, it is essential to have a strategy or plan prior to creating a model of how a unique or irregularly shaped object will be constructed from these operations and basic objects.

Solids in AutoCAD have unique properties and may be modified by operations not available to surface objects. Specifically, the commands SLICE, CAMFER, and FILLET may only be used on solid objects. Mass properties such as C.G. and moments of inertia apply only to solid objects. The plan for creating a model and the selection of which objects will compose it require a vision of how a shape may be constructed and what types of analysis will later be performed with the model. This will definitely require trade-offs between the two. However, the larger picture of other CAD tools available must also be considered. For example, both surfaces and solids created in AutoCAD may be translated via IGES as surfaces to the modeling and simulation software by SDRC, IDEAS, which can perform weight, C.G., and moment of inertia analysis with more precision than AutoCAD R13 alone is capable. Solid objects are depicted in the workspace by the edges of the planar faces that define its shape and by

lines of tesselation that show curved surfaces. Although they are termed solid objects, other solid drawing objects may occupy the same volume in space. This characteristic would enable the depiction of a fuel tank made of a solid rectangle to be placed inside a fuselage formed from solids.

A selection of AutoCAD's basic solid objects is shown Figure 4.1. The cube, sphere, cylinder, and cone were created by clicking their respective icons on the SOLIDS toolbar and following the command line prompts for size and orientation data. Their images were included here by exporting them as bitmap (.bmp) files.
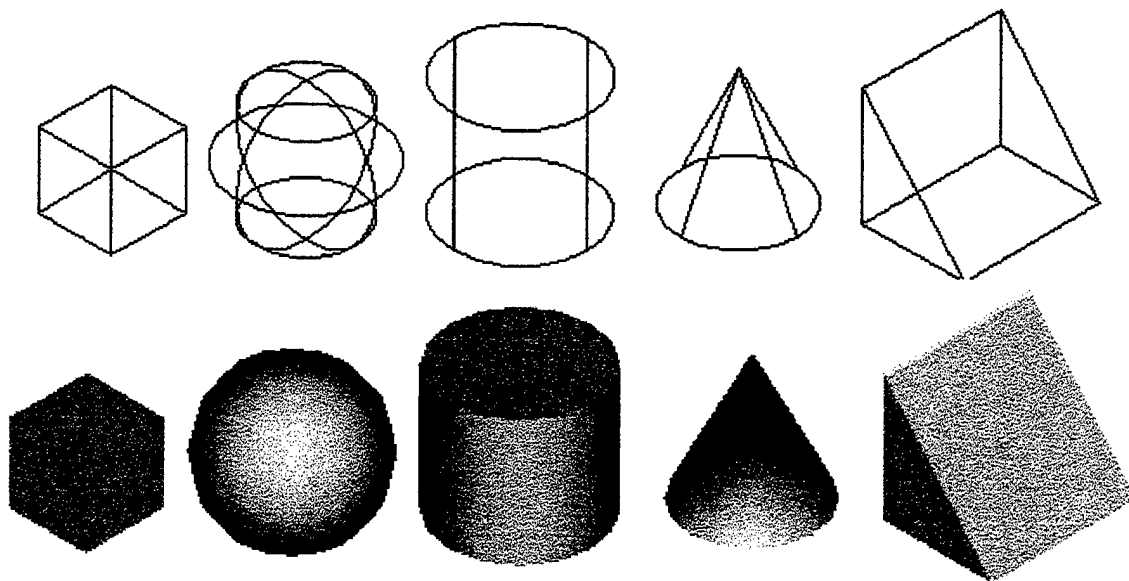
Figure 4.1 Solid Object Basic Shaped Wire-framed and Rendered Appearances

Irregular objects with a constant cross section shape, but not necessarily constant cross section size may be constructed by extruding a two dimensional closed loop object such as a circle or polygon along a path (direction and distance) defined by a line segment. This is shown in Figure 4.2.
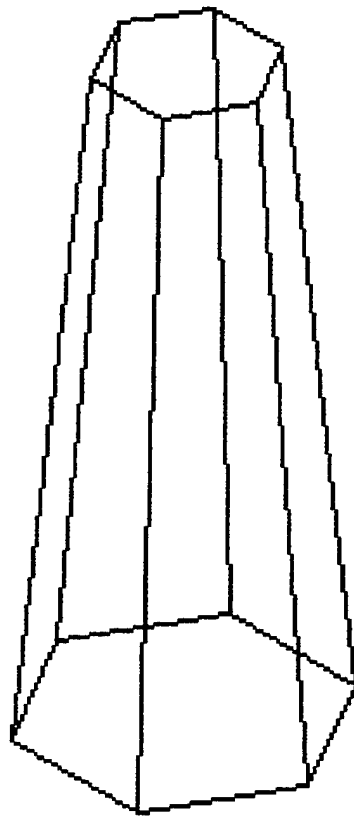
Figure 4.2 Solid Object Extruded from Hexagon with 5 Degrees of Taper

Objects that have circular cross sections such as helicopter engines or

transmissions may be constructed by revolving a two dimensional object about an axis.

This object must be a closed loop. The orientation of the axis of revolution and the angle

of rotation must be defined. This operation is shown in Figure 4.3 with a circle and a

square revolved to create a donut tire shape.
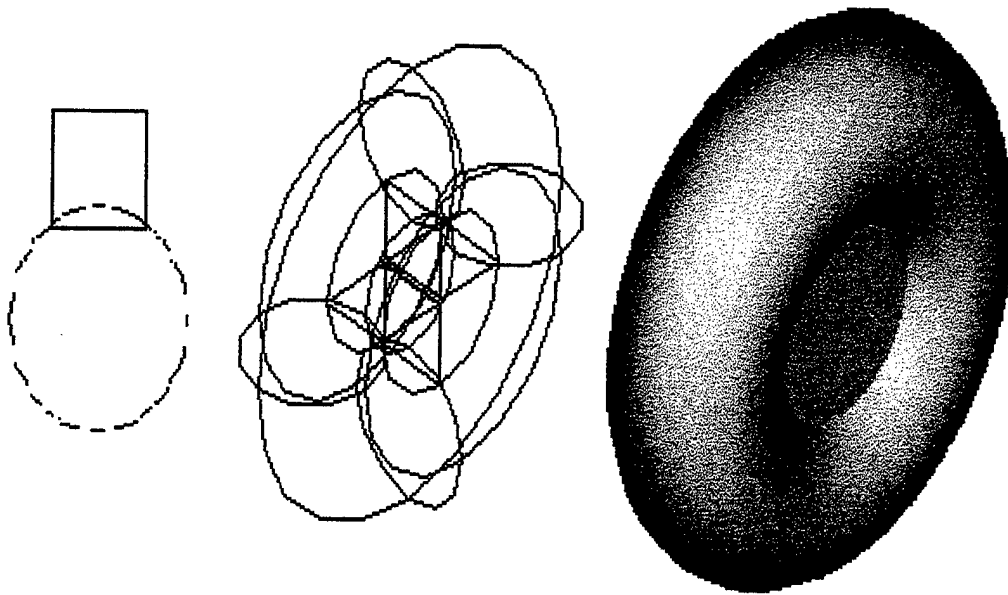
Figure 4.3 Solid of Revolution

Solid Objects may be carved down to the desired shape with the SLICE and

FILLET commands. With the SLICE command a plane of defined orientation is

intersected with a solid body [Ref. 6]. One portion is retained; the other is erased. The

orientation of the intersecting plane must be defined with three points or the geometric

equivalent thereof. Any sharp edges of the resulting object can then be smoothed with

the FILLET command. This is shown in Figure 4.4. This technique was used repeatedly

from a basic rectangular solid shape to form the nose of the VIPER model shown in

Figure 4.5.
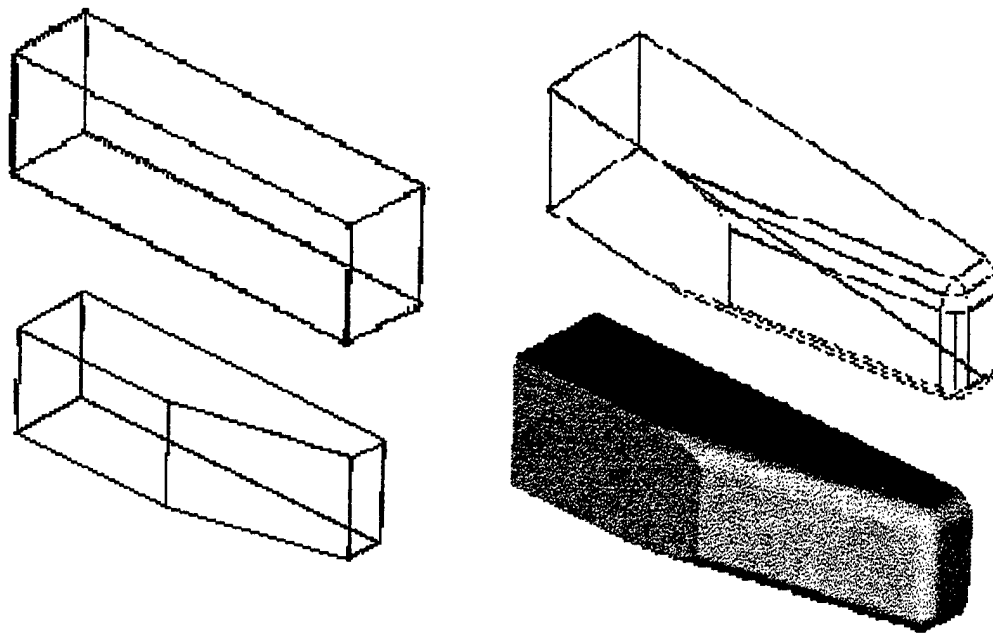
Figure 4.4 Rectangular Solid with SLICE and FILLET Operation
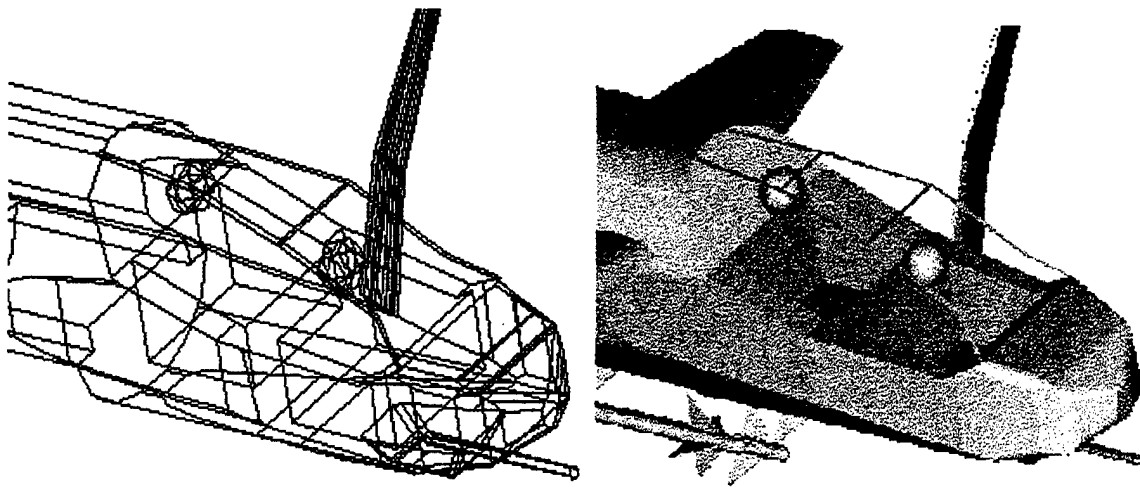
Figure 4.5 Nose of VIPER Model Created with SLICE and FILLET Operations

SUBTRACT and UNION are also essential commands to define the shape of an object. The SUBTRACT command allows a portion corresponding to the intersection of two objects to be removed from the model. This is shown in Figure 4.6 with a cylinder subtracted from the object of Figure 4.4. The cockpit of the VIPER model was created in the manner. The UNION command allows two objects to be joined just as their union in the Boolean algebra logic [Ref. 6]. There is also the capability to reverse this process with the EXPLODE command, which will break the object back up into its individual components [Ref. 6]. The commands UNION and EXPLODE are useful when it is necessary to perform a function on the entire model or on its components.

Figure 4.6 SUBTRACT Operation

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Once the geometry of an object is defined , the object may be scaled in size, rotated in it orientation, or moved in translation as the design process progresses. In Figure 4.7, the fuselage of the VIPER has been scaled larger while maintaining the basic shape of the fuselage and leaving all other objects unaltered.
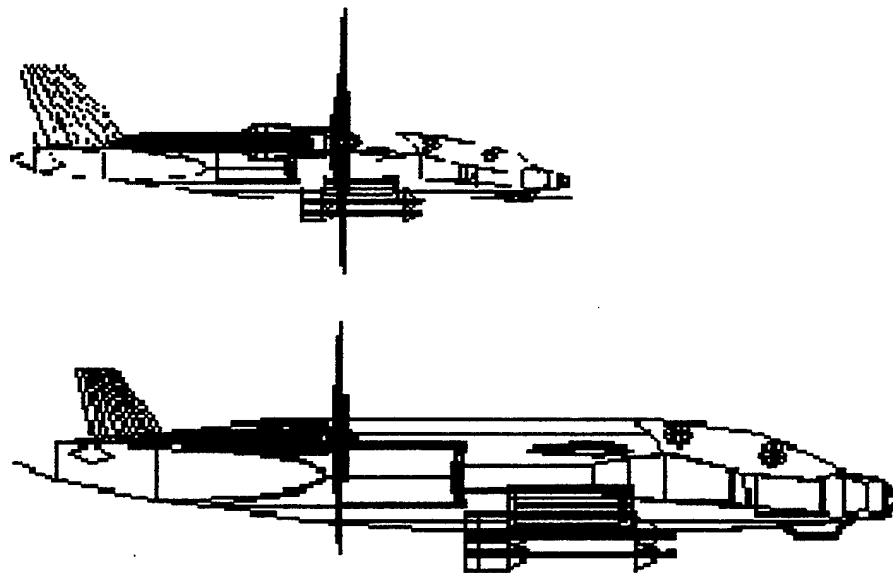
Figure 4.7 VIPER Model with Fuselage Enlarged by SCALE Operation

E.   MODELING WITH SURFACES

As is the case with solids, the use of surfaces in an AutoCAD model of an

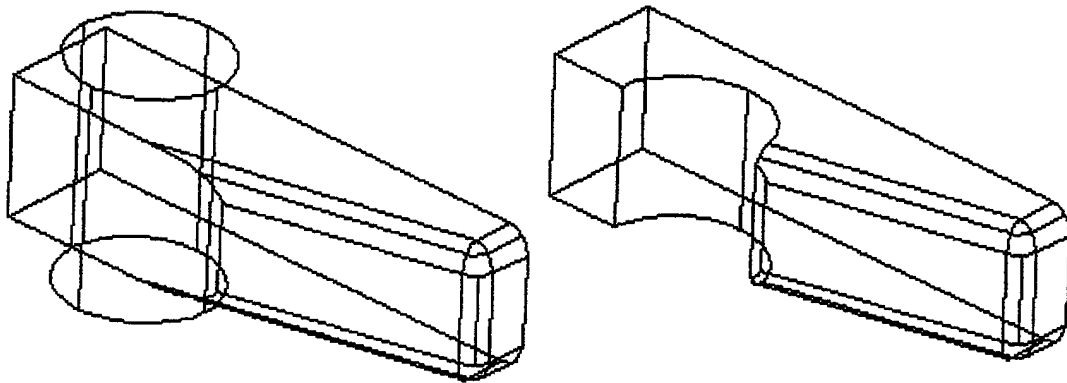aerospace vehicle requires planning for construction and vision of the model's usage

from the beginning. Surfaces also have their own unique properties, limitations, and

construction techniques. Operations such as SLICE and FILLET cannot be used on

surface objects. Some examples of basic surface objects as they appear in AutoCAD are

shown in Figure 4.8. It is important to note that while the SOLIDS and the SURFACES
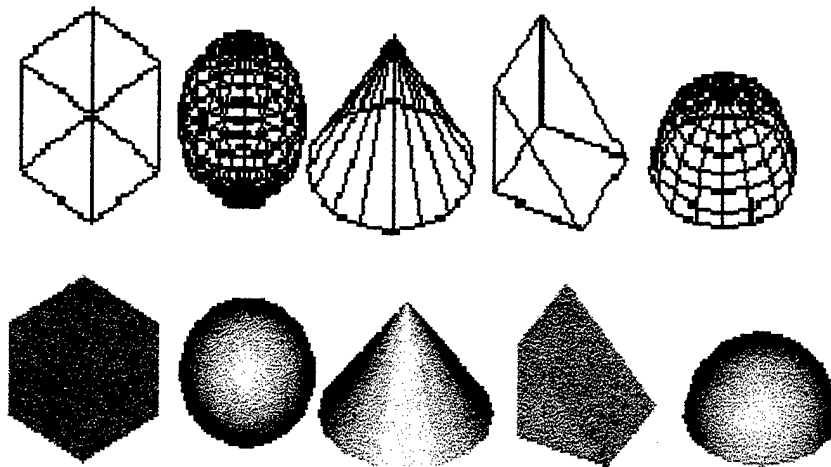
Figure 4.8 Basic Surface Object Shapes with Rendered Appearances

toolbars create some of the same basic shaped objects, their properties and the depiction

of these objects in the workspace are different. Surfaces are drawn as meshes and ruled

lines, whereas solids appear with lines on the edges of the faces and with lines of

tesselation on curved surfaces. The spacing of the mesh grid is based on the value of two

variables, SURFTAB1 and SURFTAB2. These variables may be defined via the

command prompt line. Figure 4.9 shows two domes, one with five as the value for the SURFTAB variables and the other with a value of ten. Note that it has been observed that the selection of too large a value, equating to too fine a mesh grid may cause AutoCAD R13 to crash.
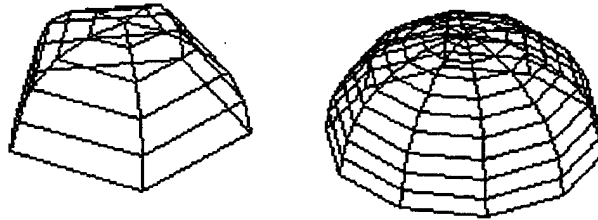
Figure 4.9 Effects of SURFTAB Variables on Mesh Spacing

Revolved and extruded objects may be used to create surfaces in the same procedure as with solids. Again the non-rendered appearance of the two types will be different. The quality of the appearance of surface objects will be determined by the spacing of the mesh grid. This is especially true in the rendering process to be discussed in Chapter V. One significant difference in properties is that the extruded solid may be constructed with a tapered cross sectional area [Ref. 6]. This is helpful when attempting to model a tapering helicopter tailboom or a tapered rotorblade.

AutoCAD possesses two tools for constructing surfaces that are particularly useful for modeling irregular shaped surfaces like those of aerospace vehicles. The RULED SURFACE command will automatically build a ruled surface between two closed loop curves [Ref. 6]. This function is used here on the VIPER to construct the tapered canards and the angled vertical stabilizers as shown in Figure 4.10. The cross-sectional airfoils at the tips and roots are joined with the ruled surface. A fuselage model

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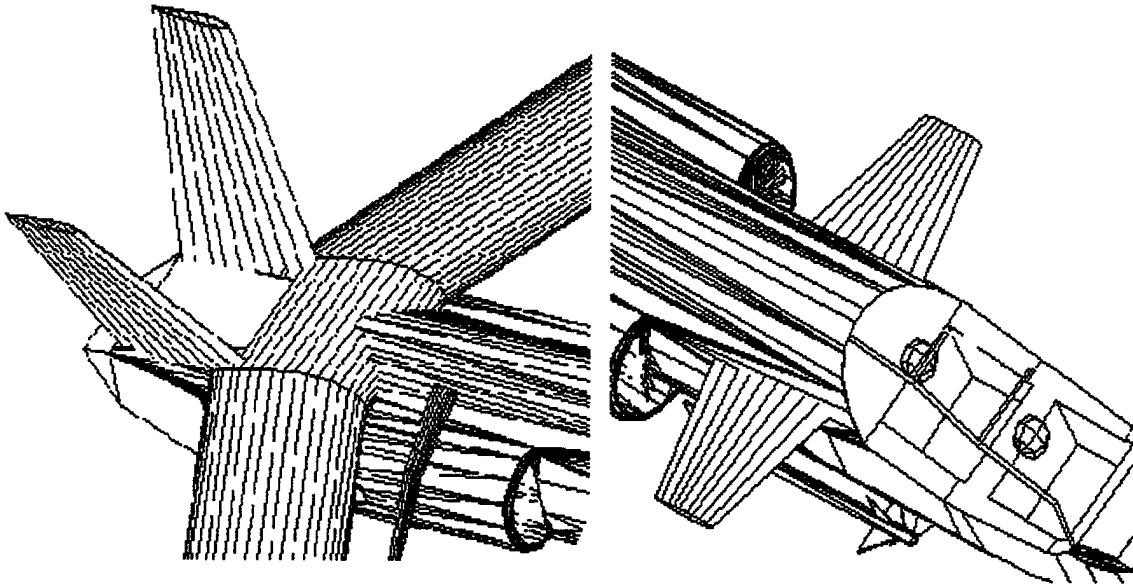
Figure 4.10 RULED SURFACE Construction of Vertical Stabilizers and Canards

could be constructed in this method using the RULED SURFACE command to join cross

sectional ellipses of a fuselage. An example of this is shown in Figure 4.11. The

EDGED SURFACE command will automatically construct a meshed surface between

four curves in space which meet end to end in a closed loop [Ref. 6]. This has the effect

of creating a patch in three-dimensional space with curved edges. Portions of or entire

fuselages may be created with patches in this manner as shown in Figure 4.12.

Additionally, patches may be created with the 3DMESH command by inputting the

vertices of the mesh in a matrix ordering. This will create surfaces with straight line-

segment edges. These are not useful in depicting most aerospace or helicopter vehicles,

but could be used to model stealth aircraft that have flat angled faces such as the F-117 or

the COMANCHE.
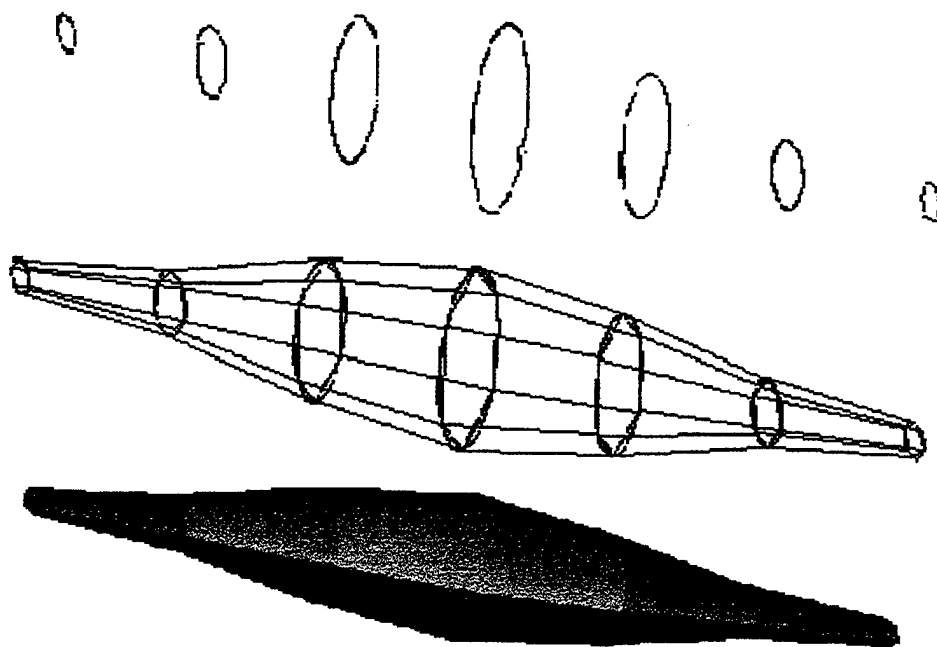
Figure 4.11 A RULED SURFACE construction of fuselage Section
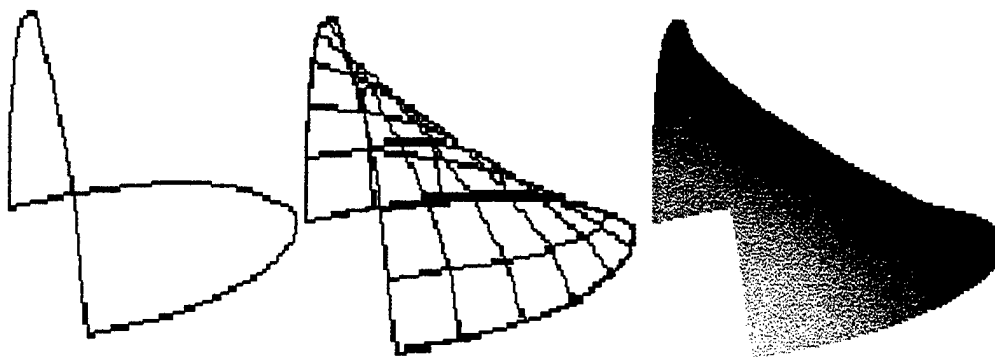
Figure 4.12 EDGE Surface patch constructed fuselage panel

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F. AUTOCAD SHORTCUTS AND TIME SAVING COMMANDS

There are a number of commands in AutoCAD that will speed the effort of constructing a model. These functions are particularly applicable to the construction of a rotary wing or aerospace model due to the multiplicity of identical parts and the axial symmetry of aircraft. Some of these commands have already been demonstrated in the exercise of Chapter II. These commands are applicable to both solid and surface objects within the model.

The most significant application is capitalizing on the typical symmetry of aircraft about the roll axis. This provides the benefit of only modeling half of the aircraft. The rest of the model is then create by using the 3DMIRROR command about the roll axis. Note that the 3DMIRROR command will create mirror images, not identical parts.

Aircraft have numerous identical parts such as rotor blades, engine compressor blades, or bomb clusters, which are not only identical, but are typically grouped in an array. This was the case with the inlet guide vanes for the engine inlets on the VIPER model. AutoCAD allows for these arrangements to be constructed quickly from a single element. The 3DARRAY command can create the entire inlet guide vane structure from a single vane by defining a polar axis for the array as in Figure 4.13.
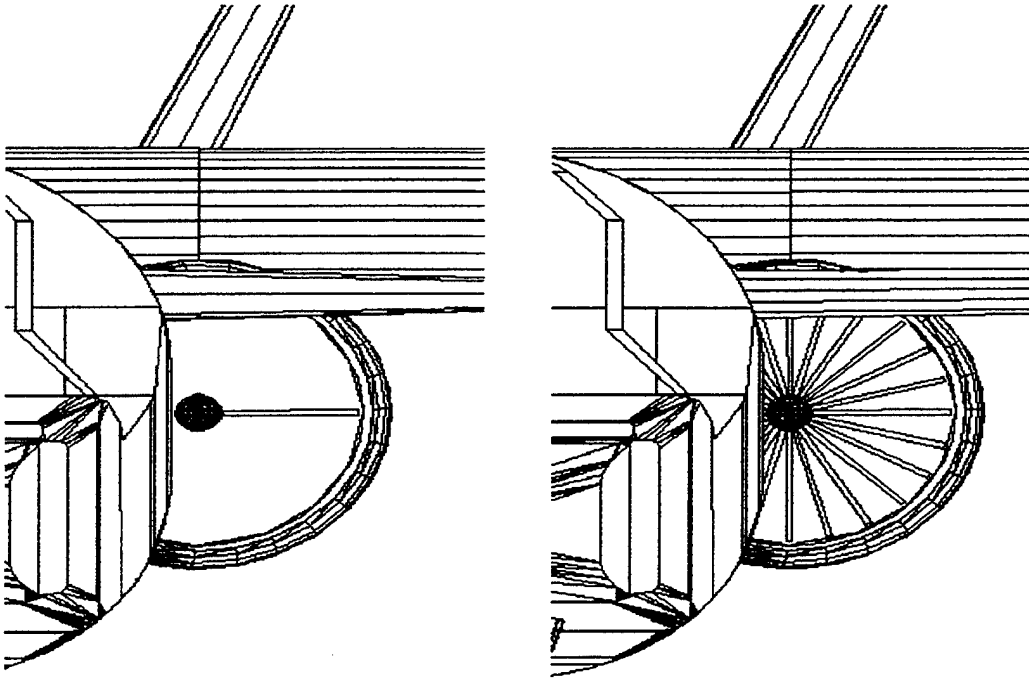
Figure 4.13 Array of Inlet Guide Vanes Created with 3DARRAY Command

G.   COMMENTS

AutoCAD provides many avenues for building a CAD aircraft model such as the

VIPER tiltrotor. Its is essential to understand the properties of the component objects

used to depict various aircraft structures and the AutoCAD operations which may be used

to modify them. The development of a useful and accurate CAD model requires a

modeling strategy to decide how the aircraft can be modeled and which techniques will

be used to model the aircraft. These decisions will be based on the nature of the design,

what can actually be depicted accurately, and what further analysis will be required of the

model. Admittedly, this requires some experience gained through trial and error.

It is important to keep a history of how the model is being constructed. This will aid in making modifications or reconstructing portions of the model. Essential to the model building process is the maintenance of a record of coordinates and sizes of objects within the model. The model coordinates should be maintained common with those used in other applications to avoid confusion when referencing component locations.

V.   ADVANCED AUTOCAD UTILITIES

A.   RENDERED IMAGES

In the helicopter design course, an ultimate goal of creating a presentation quality CAD model is the production of a realistic artistic rendering of the vehicle's appearance. A visual realization of the final design is essential in promoting a better understanding of the design concept. Mere two-dimensional orthographic views of a design can not fully project the vehicle's visualization. CAD software innovation has made computerized artistic rendering capability readily available to low cost PC's in academia and industry. The inability to incorporate this CAD feature into any academic or industrial design competition would be disadvantageous. This is true of the AHS Graduate Design Competition, where nearly all competitors use computer aided drafting tools. Many past competitors and winners have submitted computerized renderings of their proposals.

AutoCAD Revision thirteen was the first revision to include the rendering toolbox as part of the main release software package, acknowledging the importance of its utility. The NPS helicopter design team first incorporated this utility in the 1997 VIPER proposal with substantial effort. The VIPER proposal was fully depicted in rendered form as shown in Figure 5.1.

Objects constructed in the AutoCAD viewport are depicted in various wire frame schemes. Surfaces may have either ruled or meshed curved lines defining their surfaces. Solids are represented with curved lines at the edges their faces and with lines of tesselation to define curved surfaces [Ref. 6]. Once objects are rendered, solids and surfaces have the same color and texture to their outer surfaces. Rendering produces near
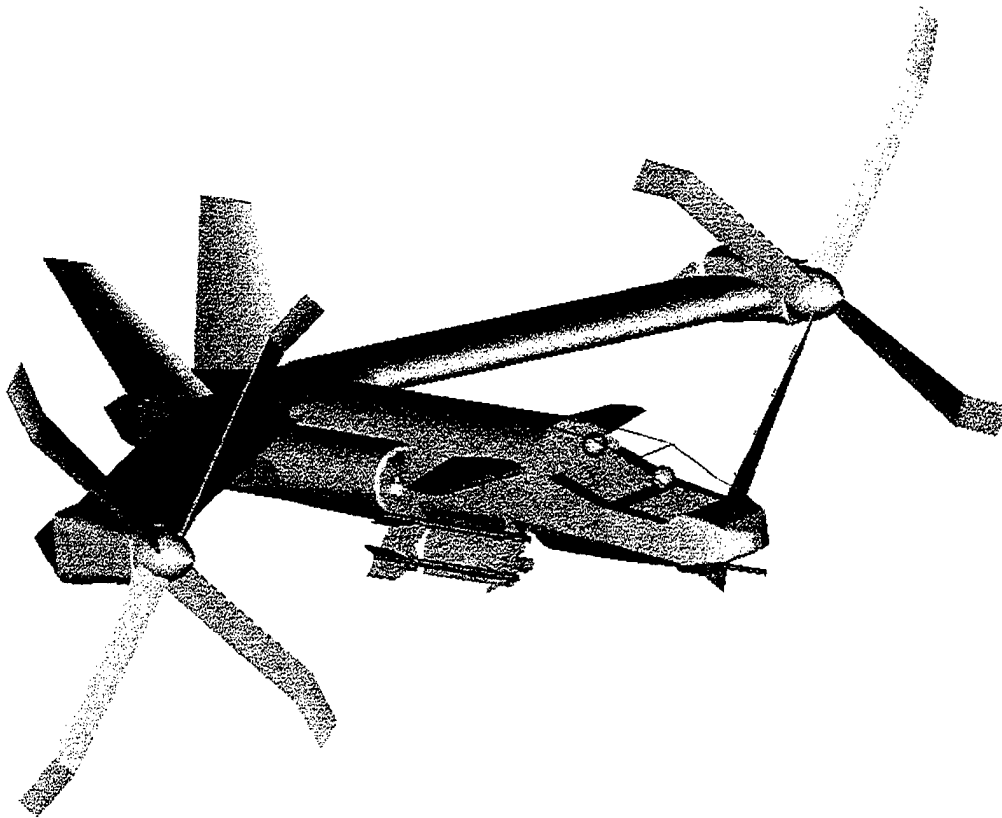
Figure 5.1 Rendering of VIPER Model

photo-realistic representations of the external surfaces of selected items in the entire

model or selected systems within the model. Rendering provides an image with proper

shading, smoothing, coloring lighting, and surface texture.

AutoCAD's render GUI window, Figure 5.2, allows for detailed configuration of

the rendering options [Ref. 6]. Smoothing angles, texture settings, object selection, and

image destination are selected in this manner. These items are also adjustable via the

render toolbar. Objects may be rendered to either the viewport or to the render window.
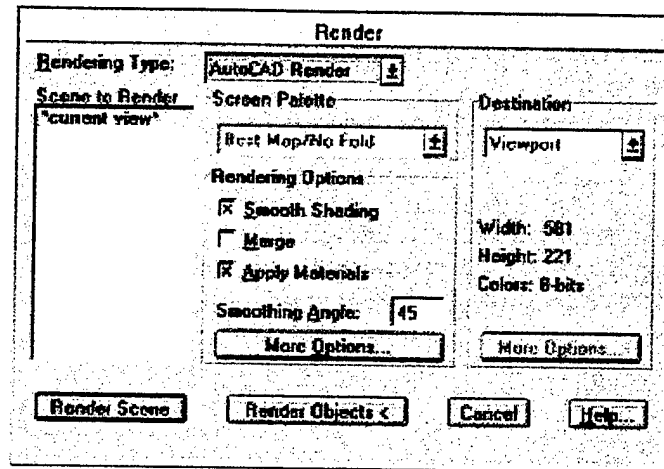
Figure 5.2 Render GUI Window [Ref. 6]

Utilization of a rendering in another application, such as was done with WORD

7.0 for this thesis and the VIPER design proposal, is accomplished by saving the image to

a graphics file. This is performed best from the render window either by copying to the

Windows '95 clipboard, or by saving the image as a .bmp extension bitmap file. From

there, it can be imported into or edited by other software. This will be necessary to print

a rendered image. It was noted in creating the VIPER model, that as a bitmap file,

degradation of the rendered image occurs with significant scaling in graphic software

such as PAINT.

The background of the rendered image will be the same as that of the background

or graphic in the viewport. Background colors are selectable from the color button on the

preferences GUI on the options menu. .GIF and .TIF graphics files can be imported into

the viewport with the GIFIN and TIFIN commands. They are two-dimensional and are

placed coplanar with the current drawing level until modified by the ROTATE3D

command [Ref. 6]. However, the quality of graphics imported into the viewport is poor.

The cover pages of the VIPER proposal were created with background images by

printing the rendered VIPER image over preprinted background images with appropriate scaling. Examples of these appear in Figures 5.3 and 5.4. These appear in grayscale for print cost savings, but were originally created in 16 bit color scaling.
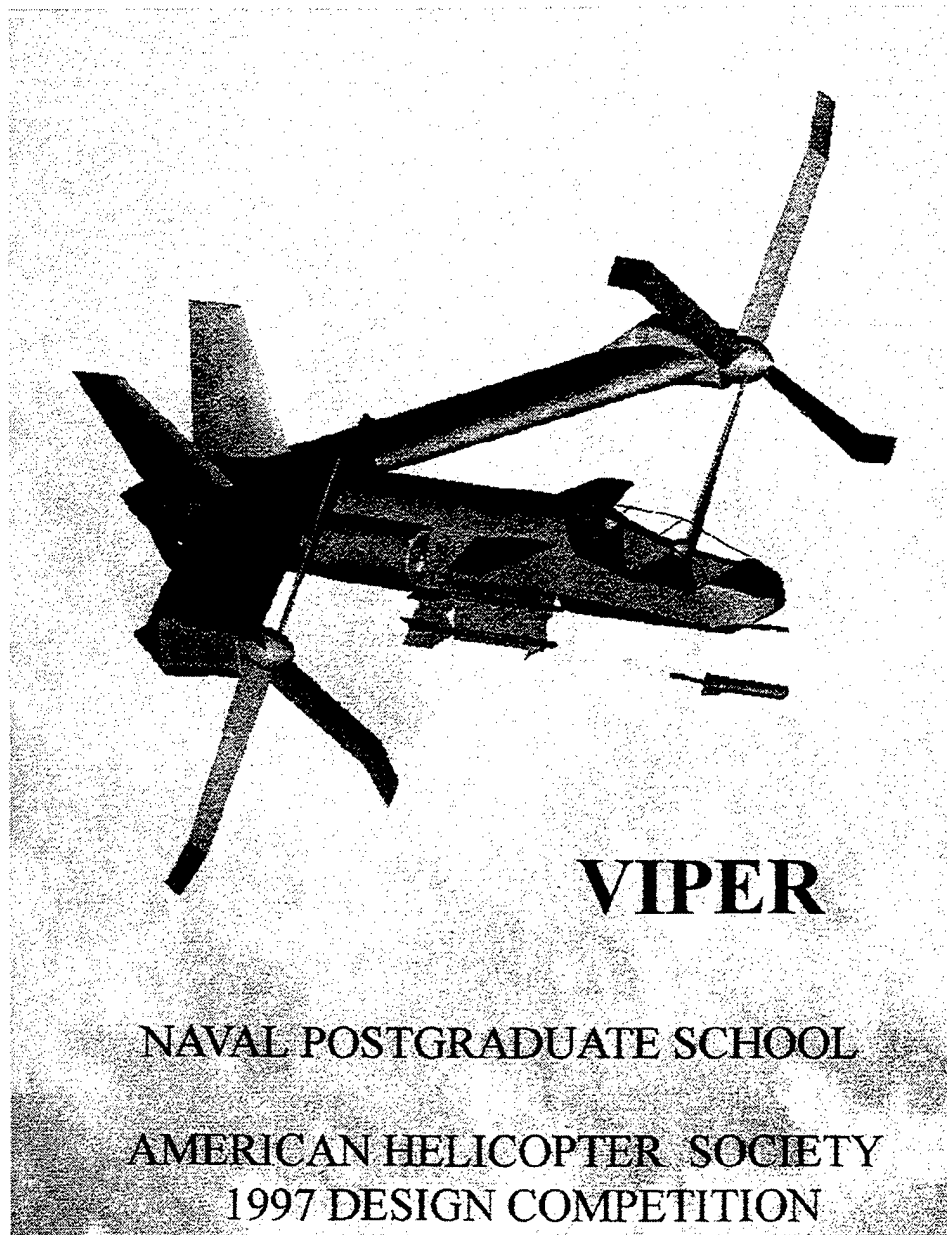
Figure5.3 VIPER Proposal Front Cover, Rendered Over Bitmap Background [Ref. 7].
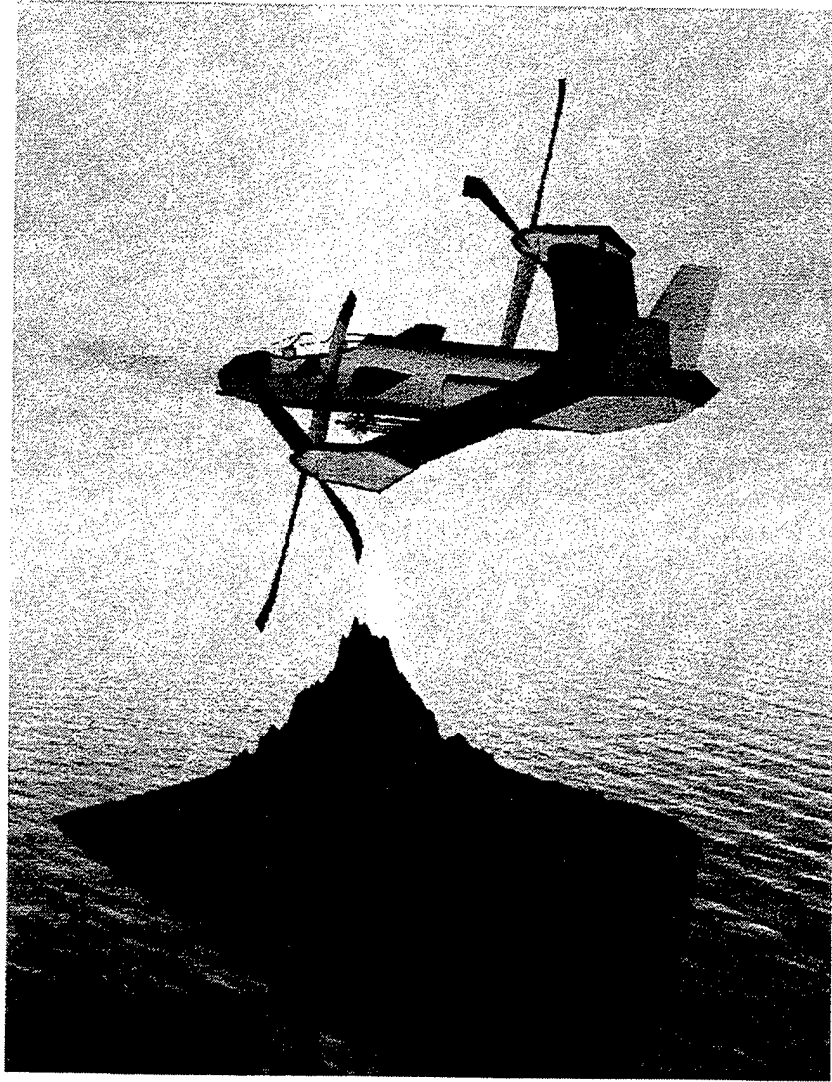
Figure 5.4 VIPER Proposal Back Cover, Rendered Over Bitmap Background [Ref. 7].

B.   DIMENSIONING

A benefit of creating the complete CAD solid model is the time saving of extracting views and data. AutoCAD facilitates the production of dimensioned drawing with automatic dimensioning. This is an enormous times savings compared to hand drafting. With the DIMENSION toolbar, dimensions are added using the mouse to select the aspect to be dimensioned. AutoCAD automatically creates leaders, extension lines,

arrows, and the precise dimension [Ref. 6]. All types of drafting standard dimension types are selectable via the toolbar. Examples of dimensioning extracted from the VIPER model for the 1997 design proposal are shown in Figures 5.5 and 5.6.
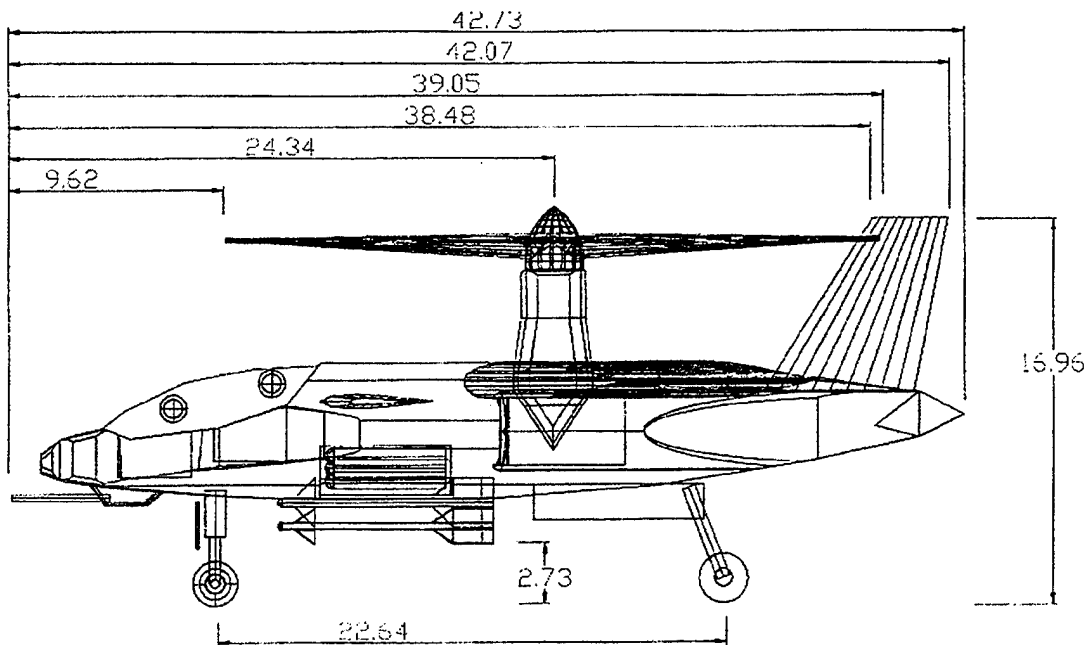
Figure5.5 Dimensioned Left View of VIPER [Ref. 7]
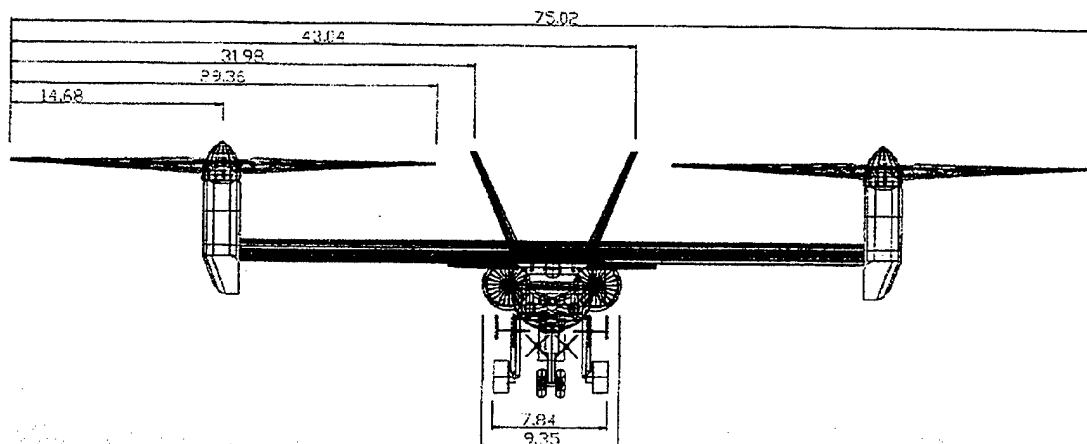
Figure 5.6 Dimensioned Front View of VIPER [Ref. 7]

It is essential to define the size and style of the text, lines, and arrows to ensure that they appear in scale with the model. The small default size of the text in AutoCAD makes it illegible when situated next to an object of size typical of an aircraft structure. Thus, the scale will need to be increased. This is accomplished via the dimension styles GUI, Figure 5.7, on the DIMENSION toolbar.
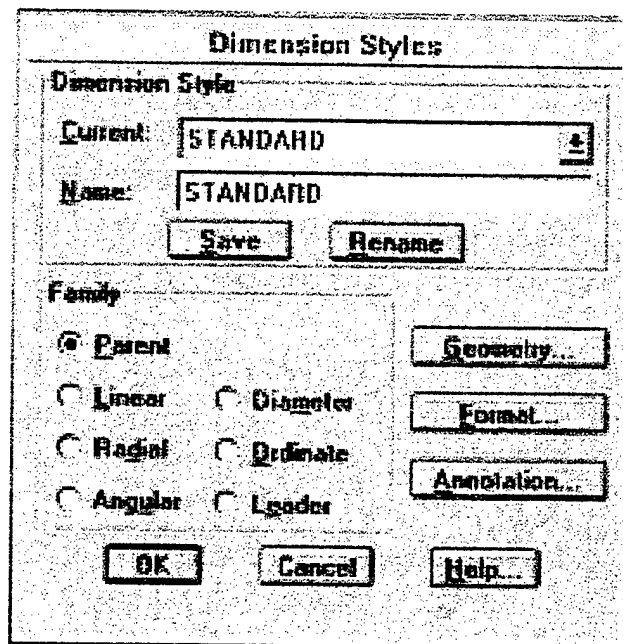
Figure 5.7 Dimension GUI window [Ref. 6]

Dimensioning can only be accomplished in X-Y planes. To create dimension of other views, it is easiest to simply rotate the entire model so that the desire view is coplanar to the drawing level. Otherwise, the dimension lines will appear, but the text will not. Also, note that dimensioning lines and text do not appear in renderings. The dimensioning will appear with the hidden line feature .

C.   PRINTING ENVIRONMENT

The printing of AutoCAD images may be accomplished directly from the AutoCAD viewport using the GUI print window or from another graphics software product after exporting the image. The highest resolution images are obtained by printing directly from AutoCAD. Images exported must be saved as bitmap files, and image data is typically lost, especially as mentioned previously in the process of scaling the image.

The GUI print window, Figure 5.8, allows previewing of the image, scaling, and feature selection such as the hidden line function. Figure 5.9 shows the gain in clarity achieved with the hidden line feature. It is helpful to select the full preview option prior to printing to ensure proper scaling and orientation. It will likely require a number of attempts with the scaling to achieve the desired graphics.
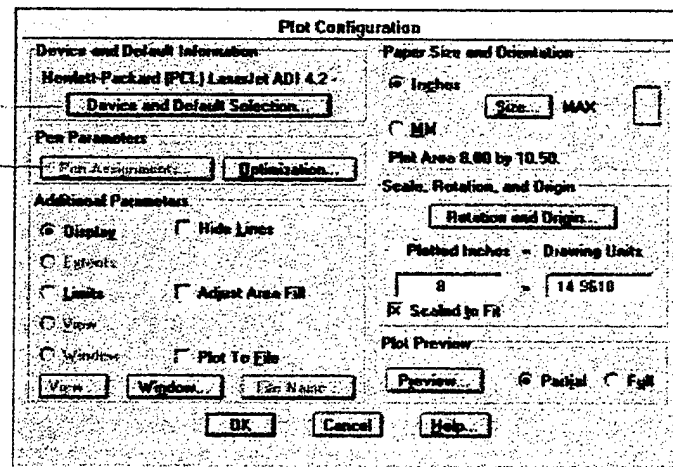
Figure 5.8 Print GUI Window [Ref. 6]
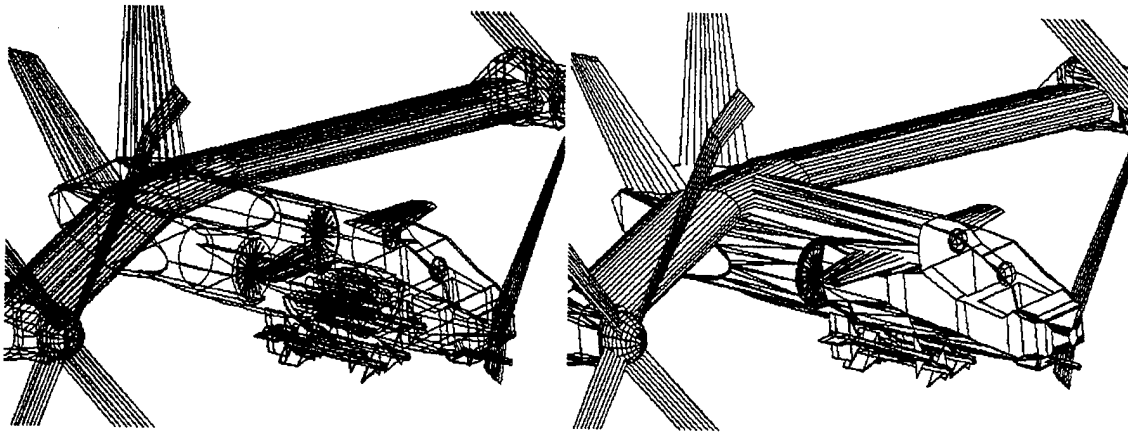
Figure 5.9 Clarity Improvement with Hidden Line Feature

D.   MASS PROPERTIES

AutoCAD solids may be analyzed for their mass properties. The command

MASSPROP will compute the centroid, volume, unit mass, moments of inertia, products

of inertia, and principle moments. This function is not available to objects composed of

surfaces. To fully exploit this utility, it would be desirable to construct the model with

solid objects to the greatest extent possible.

In it analysis of inertial properties, the main release of AutoCAD assumes a

uniform unit density of one for all objects. This obviously detracts from its usefulness to

precise analysis. For more precise analysis, an AutoCAD peripheral tool, the AutoCAD

Mechanical Desktop Designer, would permit the assignment of specific material

properties to individual components [Ref. 8], such as is available with tools in CAD

programs like IDEAS and PATRAN.

Rotary-wing aircraft are very sensitive to the close interaction of C.G. location

and travel and the control surface location for controllability and stability. Even the

crude analysis capability is helpful in analyzing the mass inertial properties of system

within the aircraft. Components, which may have irregular shapes such as transmissions

or fuel bladders, can be analyzed quickly and interactively. The relative effect of

changing the location of a component may be observed in near real time without running

a separate spreadsheet program. Table 5.1 displays the AutoCAD MASSPROP results

for the VIPER model. Table 5.2 contains the results for the same analysis with VIPER's

wing, nacelles, and proprotors move five feet forward. The change in centroid and

moment is observed.

```
---------------- SOLIDS ----------------

Mass:            1269.1577
Volume:          1269.1577
Bounding box:       X: -1.8785 -- 44.6666
                 Y: -7.2341 -- 1.7500
                 Z: -24.1848 -- 24.1848
Centroid:          X: 24.7247
                 Y: -1.4545
                 Z: 0.0000
Moments of inertia:  X: 115350.5532
                 Y: 965906.5317
                 Z: 862493.9782
Products of inertia: XY: -40761.2683
                 YZ: 0.0189
                 ZX: -0.0225
Radii of gyration:   X: 9.5335
                 Y: 27.5873
                 Z: 26.0688
Principal moments and X-Y-Z directions about centroid:
                 I: 112359.2217 along [0.9980 0.0627 0.0000]
                 J: 190364.5421 along [-0.0627 0.9980 0.0000]
                 K: 83960.6571 along [0.0000 0.0000 1.0000]
```

Table 5.1 MASSPROP Results from the VIPER Model

```
---------------- SOLIDS ----------------
```

Mass: 1269.1577
Volume: 1269.1577
Bounding box: X: -1.8785 -- 44.6666
                   Y: -7.2341 -- 1.7500
                   Z: -24.1848 -- 24.1848
Centroid: X: 23.0147
                   Y: -1.4545
                   Z: 0.0000
Moments of inertia: X: 115350.5532
                   Y: 862118.6830
                   Z: 758706.1296
Products of inertia: XY: -40780.0420
                   YZ: 0.0189
                   ZX: -0.0225
Radii of gyration: X: 9.5335
                   Y: 26.0631
                   Z: 24.4500
Principal moments and X-Y-Z directions about centroid:
                   I: 112628.0520 along [0.9998 0.0221 0.0000]
                   J: 189911.1383 along [-0.0221 0.9998 0.0000]
                   K: 83776.0837 along [0.0000 0.0000 1.0000]

Table 5.2 MASSPROP Results with Wing Shifted Forward

The capability to compute a precise volume automatically is also useful to rotary

wing design. It allows for the exact computation of fuel tank or fuselage cargo capacity.

With this tool, the percent volume devoted to individual components can be tabulated.

The AREA command is a valuable tool for drag analysis. This tool will precisely

compute the wetted area for objects selected in seconds whereas the final estimation of

the VIPER's wetted area by hand took hours to calculate. AutoCAD computed the

wetted area of VIPER as 1662 sq. feet. The hand calculation done for VIPER was 1596 sq. feet [Ref. 9]. When computing the area of more than one object, it is necessary to join them with the UNION command so that only the combined external area is calculated.

E.   IGES TRANSLATION

The Initial Graphics Exchange Specification (IGES) is used to overcome the differences in drawing file format between vendors, so that designs may be transferred between CAD programs. This allows designers to take advantage of the strengths of each system. With this utility, an AutoCAD file transfers to any system that recognizes IGES files and vice-versa. It also provides a neutral format in an industry in which each competitor promotes its own software by trying to make its own format the one of choice. The U.S. Government and industry developed IGES to ANSI standard. The government requires all contractors to provide designs in IGES format.

Ideally, everything in one system translates perfectly to another. However, each company writes its own compatible IGES translator program which work only for each release revision. Currently at NPS, the AutoCAD R13 IGES translator hasn't been able to be able to work properly, despite the use of technical documents on the home page of AutoDESK inc. or paid consulting advice.

The current method involves down-converting an AutoCAD R13 file to AutoCAD R12 format, importing the file into AutoCAD R12, and using the AutoCAD R12 IGES translator. The R12 IGES translator is a less capable program that can not fully convert R13 solid objects to R12 and does not recognize NURB surface.

The translator for AutoCAD R12 has its IGES translator inside the main program. The IGES for R13is a separate software item which is tied to specific license copy of the main program. The R13 Translator has numerous bugs. Further information can be found on AutoDESK's homepage on the Internet.

VI.   MODELING OF THE VIPER TILTROTOR

A.   CONSTRUCTION OF THE VIPER TILTROTOR SOLID MODEL

The viper tiltrotor began with the creation of its most unique features; the forward swept wings, tip nacelles, and proprotors. This process is shown sequentially in Figure 6.1. The VIPER tiltrotor wing planform has a 7.01 foot chord, 43.0 foot span, and 25 degrees of forward sweep out board of a 6 foot center wing box section. The airfoil's coordinates, based on a unit chord, were exported from the UPOT panel code program (see Appendix C) and read into MATLAB were the coordinates were scaled for the chord length and translated into the proper position in the model. The airfoil section was placed coplanar to the drawing elevation of three by using the POLYLINE as was done in Chapter II. This airfoil was then copied in place to prepare to extrude the swept and center wing sections as solid objects. Pathlines for the extrusions to follow were constructed to allow for the proper length and direction of extrusion. The wing sections were then extruded along the pathlines. The center section was then reoriented, since extrusion may only be created in the positive Z direction [Ref. 6]. The other swept wing section was created by simply mirroring the first about the X-Y plane.

The wing tip nacelles that contain the proprotor gearbox and swashplates were constructed from four rectangular solids, which were sliced and filleted as shown in Figure 6.2. The spinner was created as a solid object by revolving a polygonal section about the spinner's central axis, similar to the exercise in Chapter II.
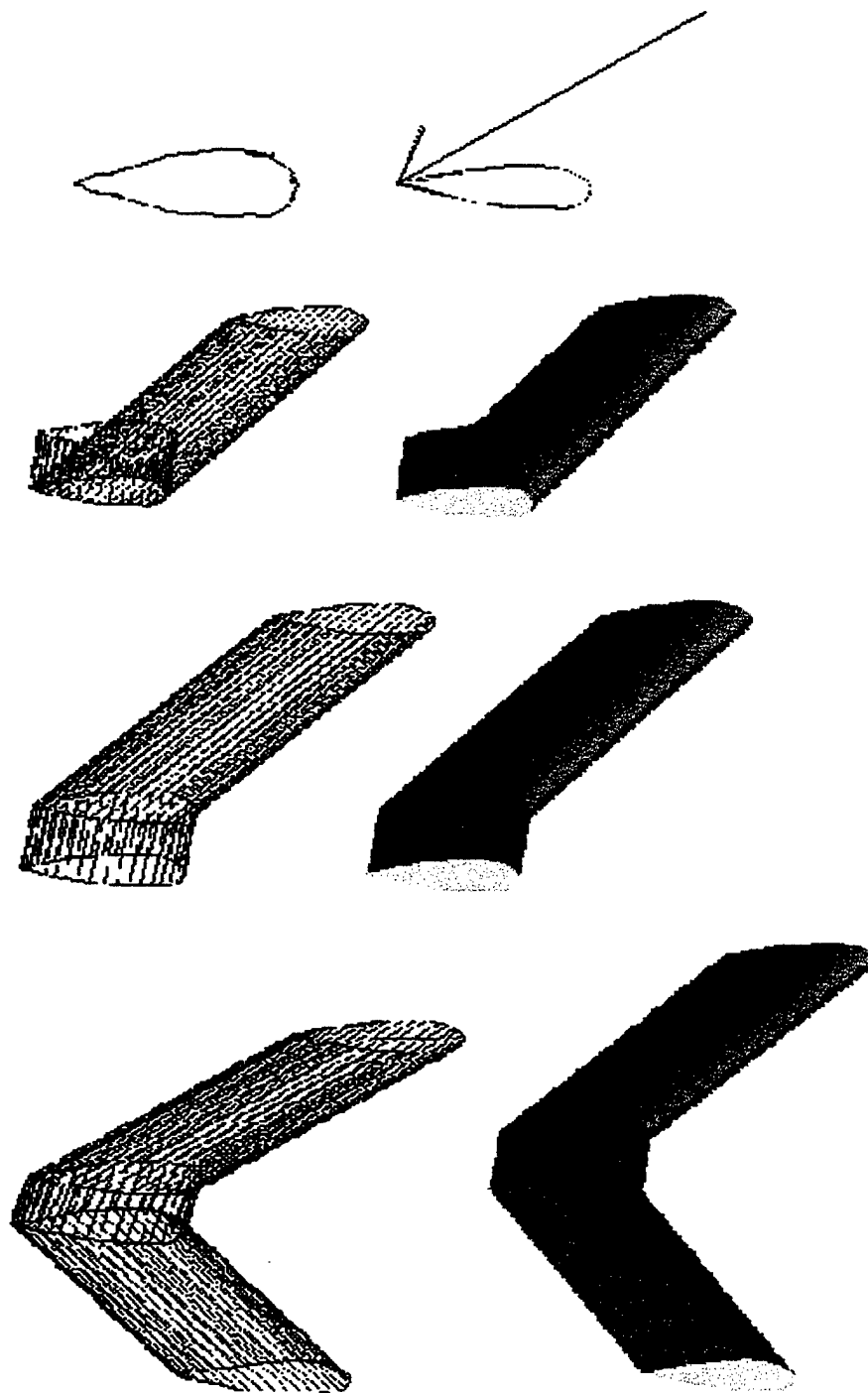
Figure 6.1 Construction of Wing
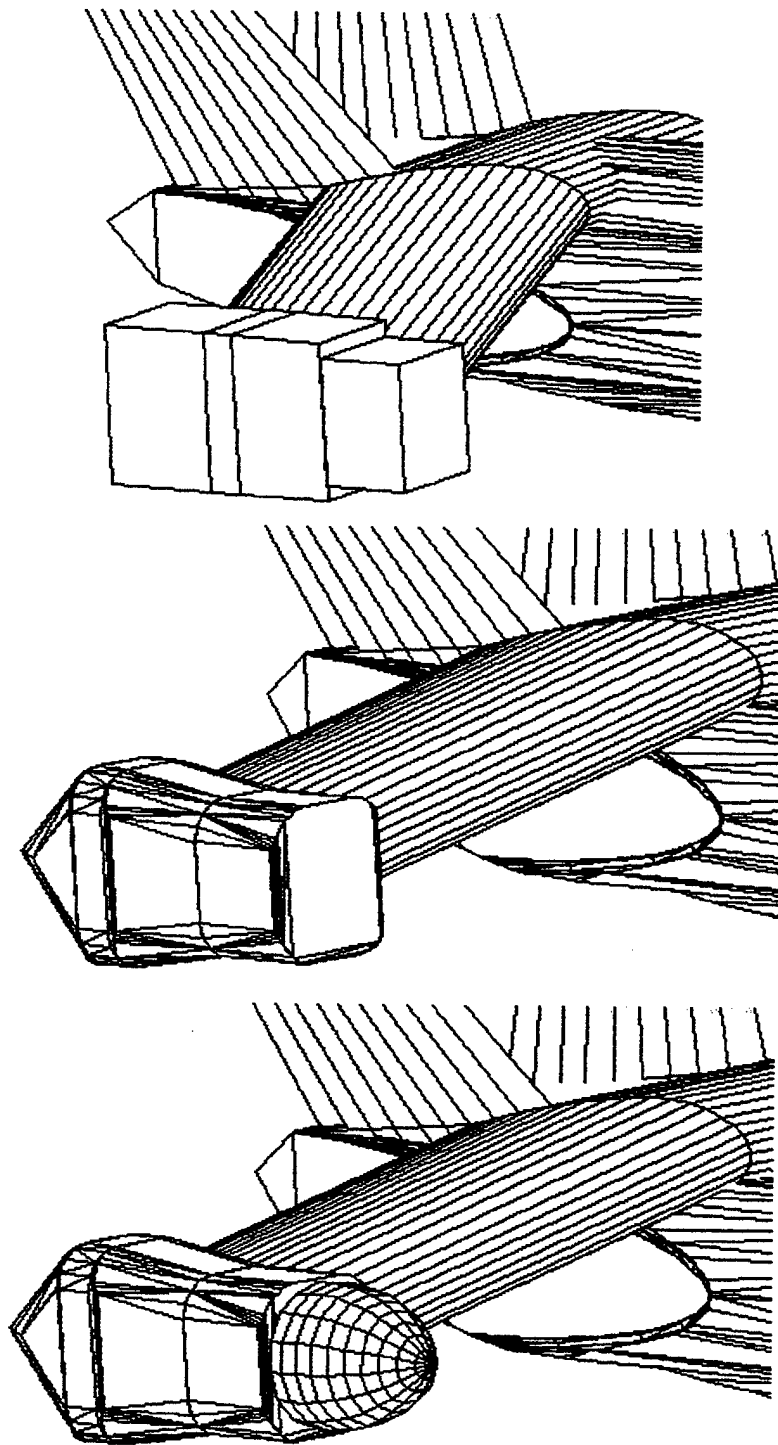
Figure 6.2 Construction of Wing Tip Nacelle

The proprotors were constructed similar to Chapter II, extruded as solid objects. The process is illustrated in Figure 6.3. As with the wing sections, the coordinates of the airfoil from which the rotor blades were extruded were extracted from UPOT and processed in MATLAB. A single rotor blade was extruded along a pathline that accounted for the 20-degree sweep of the tip. This pathline was a polyline rather than two line segments so that the blade could be created with a single extrusion. The remaining of the blades were constructed with the 3DARRAY command as in Chapter II. The opposite proprotor was created with the MIRROR3D command. The blades had a chord of 1.75 feet and a span of 14.6 feet with the outer 2.9 feet swept at 20 degrees [Ref. 7]. The blades had a constant chord, but could have been extruded with a taper angle if the design has specified.

The fuselage of the VIPER design had a rounded cross section, which was not circular or elliptical. The fuselage required an aerodynamic body to house all components and have a forward, tandem cockpit. The nose was to have faceted surfaces to provide stealth features. The bottom required some flatness for the placement of the missiles. These requirements were met by carving and filleting a solid rectangular section. This is illustrated in Figure 6.4. First, the longitudinal edges of the rectangle were first filleted. Planes, whose slopes increased as they approached the leading and trailing edges, progressively sliced the nose and tail of the fuselage section. The edges of the nose were then further smoothed with the FILLET command. First slicing out the section housed by the canopy and then subtracting rectangular solids for the crew spaces removed the volume needed for the cockpit to be depicted.
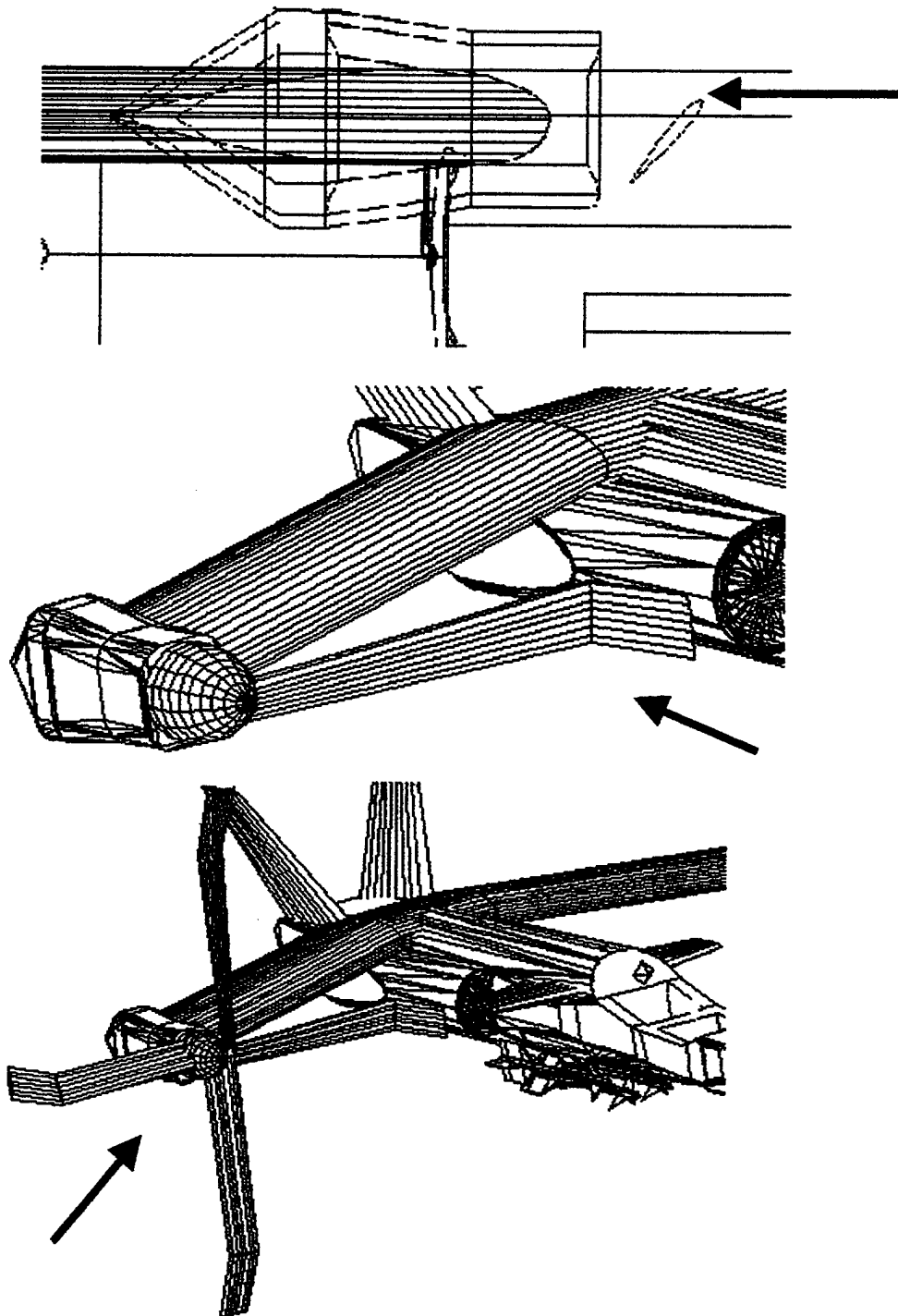
Figure 6.3 Construction of Proprotor System
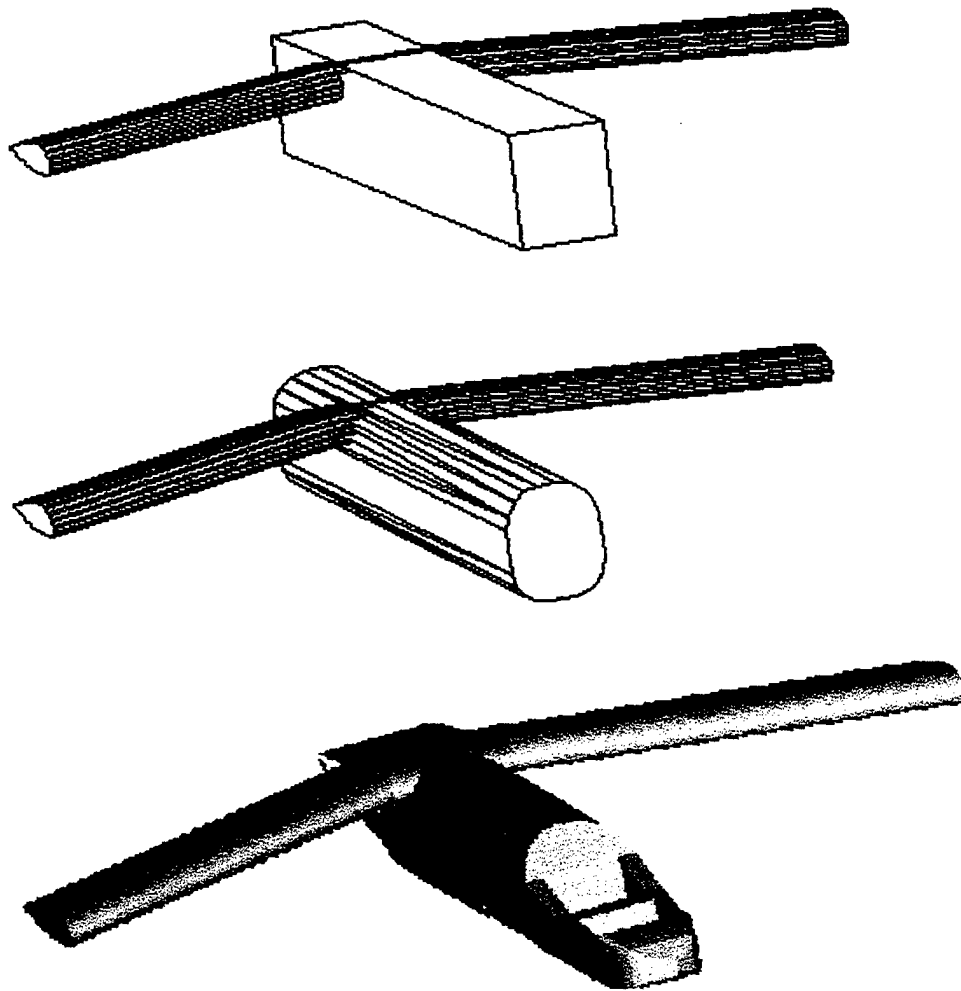
Figure 6.4 Construction of Solid Model of Fuselage

The engine volume was then added to either side of the fuselage. This was

accomplished using the UNION command to add cylinders, which were partially

embedded in the fuselage with an air inlet area of approximately half of the engine cross

section. The engine inlet guide vanes, Figure 4.13, were added for appearance only. A

single vane was constructed as a solid. The remaining blades were created similarly to

the proprotor blades.

The vertical stabilizers of the VIPER are tapered as well as slanted aft and to the sides. A root airfoil cross section constructed of a polyline was extruded along the pathline of the leading edge with a taper angle. The airfoil was a standard NACA 0012 with airfoil coordinates extracted from UPOT and MATLAB similar to that of the wing sections. The canards were created in the same manner, but with a pathline of the quarter-chord line perpendicular to the root airfoil section. The canard airfoil was a NACA 0012. For both the stabilizers and the canards, only a single solid was constructed. The opposite pair of fins was created with mirroring.

Construction of the weapons bay, Figure 6.5, was accomplished by subtracting the intersection of a rectangular solid with the fuselage to create a semi-circular solid. The center on this part was then scooped out by subtracting a slightly smaller identically
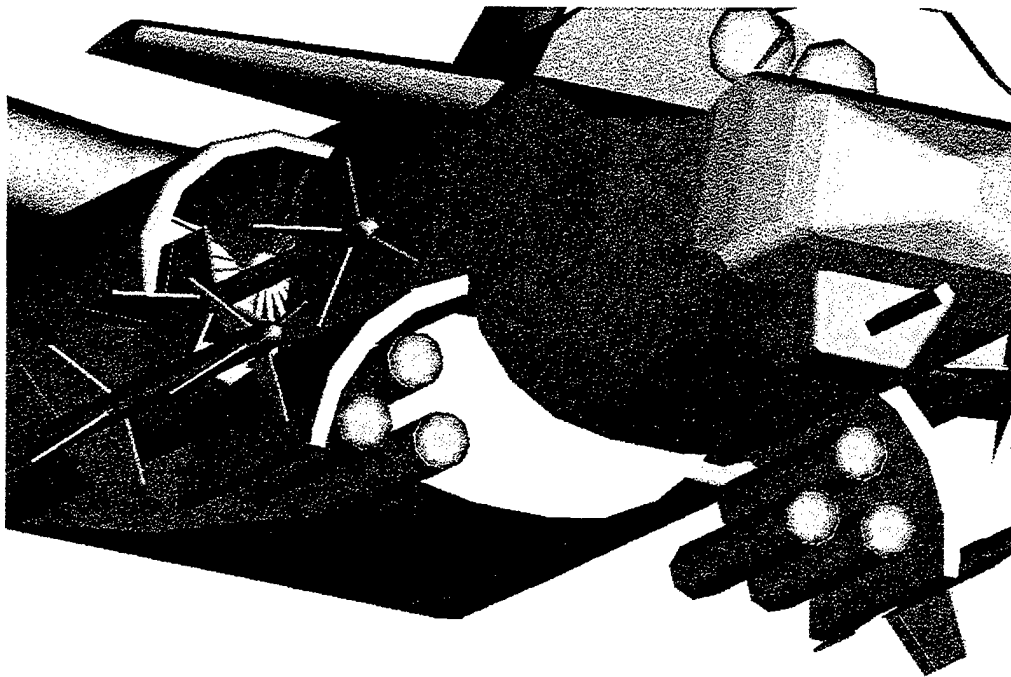
Figure 6.5 VIPER Weapons Bay with Hellfire and Sidewinder Missiles

shaped solid. This remaining semi-shell was then cut in half with the SLICE command resulting in two weapons bay doors. These weapon bay doors could then be depicted as opened or closed using the ROTATE3D command.

Internal components of the VIPER were constructed with methods similar to those describe above. For the design proposal, a transmission system, fuel tanks, and weapons were constructed, Figure 6.6. It is important to note that although these internal components were constructed as solid objects, they are able to occupy the same volume as the wings and fuselage. They are distinct solid objects shown to occupy the same space. When rendered, only the external surfaces of all objects selected will be visible. These components may be analyzed separately for their mass properties.
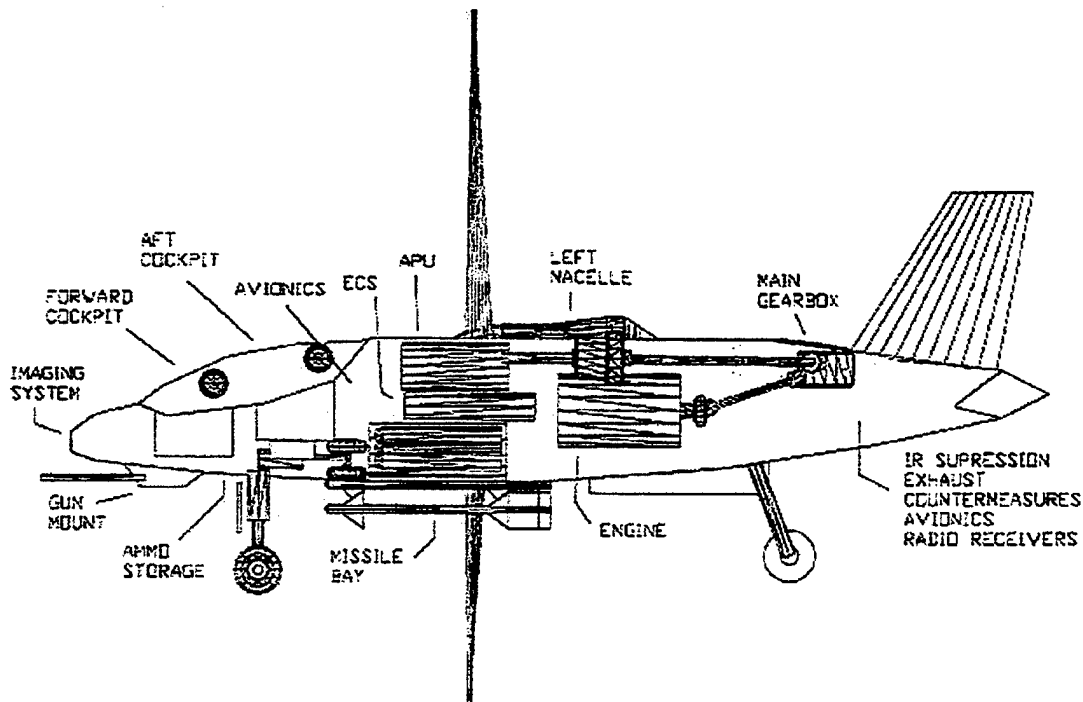
Figure 6.6 Cutaway View of Internal Components [Ref. 7]

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B. LESSONS LEARNED

The solid modeling of the VIPER design began without any prior experience in modern CAD systems by team members. Due to lack of funding and time, it was not possible for team members to attend an AutoCAD instruction course as is done with students in the TSS curriculum at NPS. This resulted in a steep learning curve while carrying out the design process.

It was soon realized that not everything that could be conceptualized on paper could be easily constructed with the tools available in AutoCAD. Those techniques that were successful were learned by extensive trial and error. This involved a substantial time investment. Although there are texts and guides available, they are thick and often very generalized in their applications. They also lack the documentation of flaws in the software and operations that cause AutoCAD to crash with loss of data. Some of this knowledge was better obtained off the Internet where users compile their experiences on news group pages [Ref. 10]. The construction of a rotary-winged vehicle such as the VIPER requires some unique methods to create very irregular parts. Due to lack of prior experience, the model sometimes drove the design instead of the design driving the model. However, this was likely a very realistic learning experience. With modern computer aided design and manufacturing, only those objects that can be described in the CAD system can be analyzed and manufactured [Ref. 4].

The time required to both learn AutoCAD's use and to create the VIPER model limited both the detail given to internal components within the model and the analysis performed on the model. Additionally, the effort of creating the model was replicated for the finite element structural analysis due to the project timeline and the quality of detail

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for which the IGES translator was capable. The entire AutoCAD model could not be imported into PATRAN for the wing structure design and analysis. A separate and identical model of the wing was built with PATRAN for this purpose. The overall effect was to limit the total man-hours that could be devoted to the design analysis.

It was observed that there is potential to capitalize on increased use of computer aided design and analysis and the increased integration of CAD resources available to the helicopter design course project. The use of AutoCAD has the advantage of being able to operate in a Windows '95 environment on a low cost PC. Also, AutoCAD's purchase price is comparable to items such as MATLAB and OFFICE. This enables quick integration with MICROSOFT OFFICE word processing and presentation software that is typically owned by student team members and available to them at their convenience. AutoCAD images are then easily integrated with other widely known and user-friendly graphics program such as Paint and COREL PHOTO-PAINT for quick editing. Plotting can also be accomplished with the current generation of low cost PC compatible printers independently of a large UNIX network. The capability to translate AutoCAD model data for use in other CAD systems such as NASTRAN and IDEAS will reduce time lost replicating models while increasing time for analysis.

The use of solid modeling and computer aided design and analysis allowed for better visualization of aircraft real estate, the volumetric space available for components and their precise placement. In the design of the wing, there were numerous iterations of the volume available in the wing for the fuel and that space needed for structural frames. The framing of the wing was designed by MAJ. Brian Shoop, USA with PATRAN and is shown in Figure 6.7. Additionally, the wing volume had to be shared with the
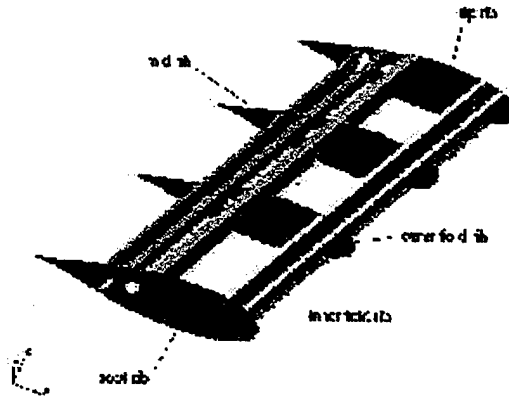
Figure 6.7 Structural Framing of Wing [Ref. 11]

transmission system drive shafts from the main transmission to the wing nacelles, Figure

6.8. The placement and design of the systems was better visualized and analyzed with

the solid models. However, this could have been made simpler with the complete

integration of all design efforts in one solid model accessible to all team members.
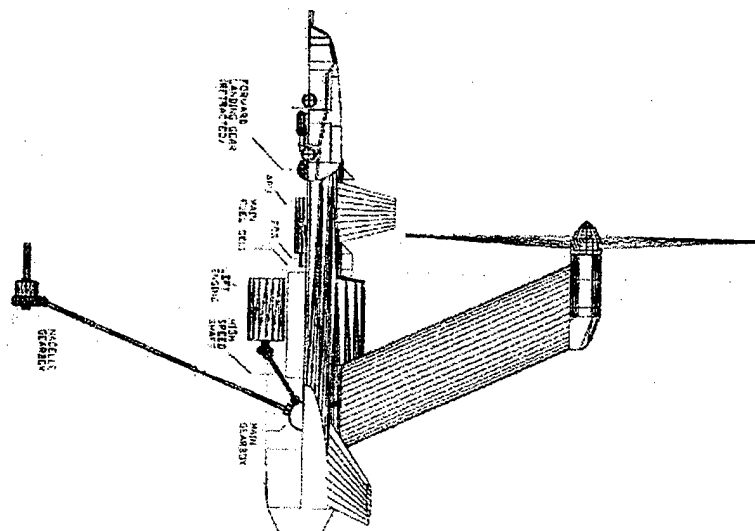
Figure 6.8 Cutaway Revealing Transmission Drive Shafts [Ref. 7]

The initial graphics and conceptualization of the VIPER's appearance and design were accomplished by the dedicated and talented efforts of LCDR Chris Laplacik. It was from his skilled hand drafted orthographic projections that the VIPER CAD solid model was created. His work is gratefully acknowledged in Figures 6.9, 6.10,6.11. It is desired that as a result of this thesis and the experience of the VIPER model, that such detailed hand drafting will not be required for future AA 4306 projects, and that CAD modeling will occur earlier in the visualization and modeling efforts.

The capability of CAD solid modeling to create pictures of the VIPER also helped substantially in creating an aesthetically pleasing design. Although the importance of a design course is in the engineering analysis and technical accuracy, any industrial design team competing for a helicopter contract will acknowledge the significance of selling a good looking vehicle.
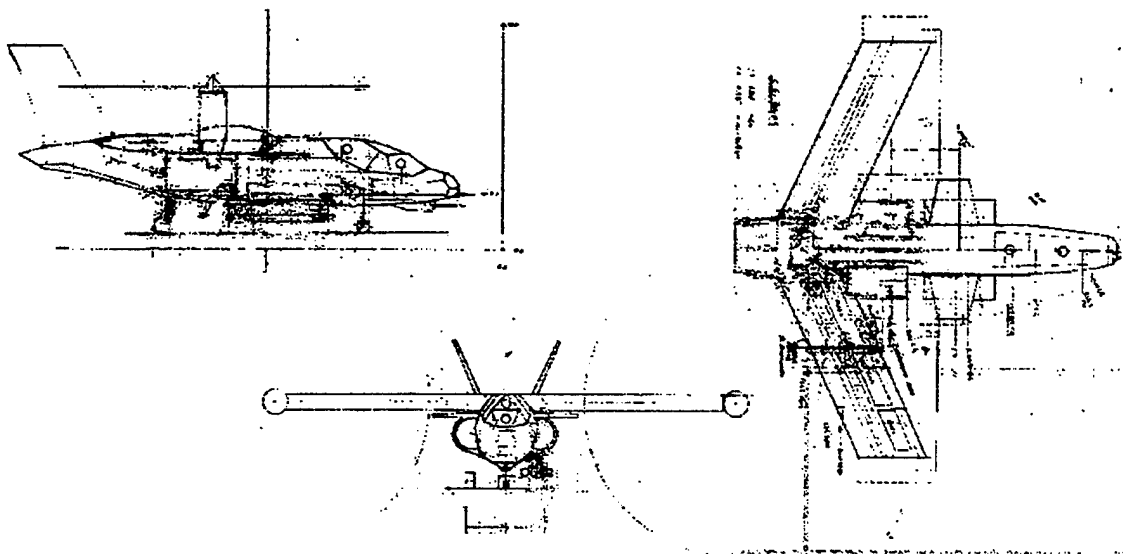
Figure 6.9 Initial Sketches of VIPER Concept [Ref. 12]

VII.   CONCLUSIONS

Computer Aided Design and Manufacturing is an integral part of modern industry. The Naval Postgraduate School prepares its students to become weapons systems project managers and to liaison with the defense industry. It is essential to develop an understanding of the design technology and principles used in the production of defense systems. Engineering design educational institutions in general have begun to focus more attention on CAD education to meet the demands of industry. Most companies hiring new engineering graduates desire familiarity with three-dimensional visualization as a minimum CAD experience [Ref. 13].

The VIPER CAD effort resulted in a high-quality, realistic three-dimensional solid model visualization of the design concept. There was a steep learning curve to overcome in learning the intricacies and pitfalls of AutoCAD. Although a finalized model was achieved by the end of the design quarter, full utilization of the benefits of solid modeling and AutoCAD did not occur. This guide with its application specific approach, practice exercise, and VIPER lessons learned, will greatly reduce the learning investment required. Future students will use this work to gain a quick understanding of AutoCAD, build models rapidly, and invest the design quarter analyzing the data from their modeling.

The commands, skills, and techniques explored here will enable NPS students to create full, detailed, and realistic solid models. This material likely will be of use to the fixed-wing and missile design courses also.

It is not expected that students will gain the CAD proficiency level of professionals. AutoCAD professional training courses range in time from a few months to a year or more [Ref. 4]. It is reasonable to develop enough skills to model their concept, analyze its parameters, evaluate design merit, and communicate their ideas in a clear, powerful, and convincing presentation. The value in educational improvement comes from using the tool during the design iterations to relate individual effort to the team goals. AUTODESK Inc. believes the communication of ideas value of CAD to be critical. They have formatted the AutoCAD .dwf drawing files to be compatible for use and transmission on the Internet to build rapid design processes with larger teams [Ref. 4].

The use of CAD as an integral tool as an integral tool throughout the preliminary design phase of AA 4306 is an achievable goal. This guide will allow the team members to acquire sufficient skills by the beginning of the design course. The initial design graphics will go straight from 'back of the envelope concepts' to three-dimensional rendered visualization. Each team member will add their system design data to the complete solid model and analyze its integration with the entire model's parameters. Rough estimations of C.G. displacement and moments of inertia with the location of systems will be analyzed interactively in the solid model. Conflicts between system criteria will be quickly identified.

The database comprised by the solid model will be useful for analysis in other CAD applications. With full use of the IGES translator, the geometry of the model may be fully imported into PATRAN for use in NASTRAN analysis. Portions of the model

could be exported for aerodynamic code analysis via GRIDGEN if required. The Geometrical data with the AREA and VOLUME functions in AutoCAD will aid in the computation of stability derivatives for dynamic analysis.

AutoCAD solid modeling is an ideal approach to the AHS design project. It is a low cost and low maintenance CAD product. AutoCAD R13 will run on a low cost Pentium personal computers currently on the market.

The skills needed to perform solid modeling on the AA 4306 project are a narrower, more focussed subset of AutoCAD's capabilities. However, they need to be learned in the context of the unique and irregular structures and shapes of rotary-winged aircraft. With a modest investment of time to learn these tools, each team member could acquire a useful proficiency. Preferably, at least one team member with further pursue its use and become the teams expert in the subject in order to maintain the overall model. Although AutoCAD requires an initial time investment, the payoff will come in reduced time for design iteration and analysis.

Greater team cohesion and understanding of the design progress will be achieved by using solid modeling as a common tool to integrate the efforts of each area of design specialization. Ultimately, a more detailed, professional, and quality design project will result. The educational benefits will include learning design in amore realistic environment using modern tools.

VIII. RECOMMENDATIONS

A. DESIGN EDUCATION

Previous design teams have relied on faculty from other departments to provide some limited CAD instruction. The Mechanical Engineering department sends a few of its TSS students TAD to a paid tuition instruction course. It is essential to begin the helicopter design project with a CAD capability. However, it should not be necessary for faculty to provide formal basic CAD instruction in a graduate curriculum. This thesis and the VIPER project demonstrate the means of acquiring essential skills through self-study and proper lead-in time with useful resources. These students are identified two quarters prior to the design course. It would be to their benefit to pursue this goal. It is recommended to provide this guide to all students of the three vehicle design courses one quarter prior to commencing their design projects.

B. FACILITIES IMPROVEMENT

The VIPER project would not have attained the level of analysis and educational benefit that was achieved without the availability of the personal computing assets of the faculty advisor and team members. Although the Aeronautical Engineering department has a dedicated, spacious facility for use by three design courses, the maintenance of the facility's equipment and the enforcement of its operating procedures inhibit the design education.

Design modeling and analysis in the academic environment is best conducted with personal computer. The characteristics of the UNIX system are not favorable to the use of design software. The availability of finite numbers of licensed copies of software

and the access time to programs and data on shared disks present difficulties. The shared use of terminal processors slows down the operation of the software. These factors made the choice of IDEAS on the network undesirable for the VIPER project. IDEAS on the department's UNIX network runs slow and often the licensed copies are in use by others. The most favorable environment is the PC. It is the computer most widely used and best understood by students. PC's use the software most familiar to students. AutoCAD R13 runs very fast on high speed Pentium processor with adequate memory.

The design courses need powerful, stand alone PC's with Pentium MMX processors. For design applications, these systems require large monitors and high capacity floppy drives. Most of the VIPER's solid modeling was performed on a 166MHz MMX Pentium PC with 64MB of RAM. It was also attempted on a 133 MHz system with 24 MB of RAM. The difference in speed of the program and ease of display was substantial. The 133 MHz system tended to lock up or crash frequently during computation intensive operations such as dynamic viewing and rendering. The 133 MHz system could not support dynamic viewing. The 166 MHz MMX was just capable of keeping up with this utility. The minimum requirements for running AutoCAD R13 are listed as a 486 processor with at least 8 MB of RAM devoted solely to its application. This would clearly be unsatisfactory on a Window operating system. However, recent drastic price reductions have made 200 MHz MMX and faster machines affordable.

The lab currently has three PC's. Two are 486 IBM type machines while the third is a 133 MHz Pentium system with 16 MB of RAM. While this equipment is adequate for word processing or MATLAB (although the JANRAD program runs slow on the Pentium), they are not truly CAD capable machines. Additionally, the Pentium machine

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was out of service or disassembled for the majority of the design quarter. The remaining PC's were constantly plagued by viruses due to frequent use by all students as word processing workhorses. The design lab must truly have capable, dedicated design PC's with their use controlled and limited to design course work. Student word processing is also essential to education and deserves its own resources.

CAD and numerical analysis software generate large data files that can not be transferred or stored by 1.44 MB floppy diskettes. The current VIPER .dwg files approaches 3 MB of data. The lab requires the addition of a large capacity, high access speed floppy drive such as the 100 MB ZIP drives.

C.   SOFTWARE

The design lab currently uses Windows 3.1 for an operating system and WORD 6.0 for word processing on its PC's. It would be preferable to upgrade to the operating software and software used by most student. Window '95 and OFFICE '97 would be more compatible with most student's own software.

The AutoCAD R13 program needs to be maintained operational on at least one PC in the design lab. It is loaded on the lab's Pentium computer, but has seldom been operational, even when the Pentium computer was actually working. Ideally, an appeal should be made to acquire AutoCAD R14 educational grant software. This program was recently terminated. The addition of some of the peripheral AutoCAD toolboxes such as MECHANICAL DESKTOP would provide better solid modeling analysis capability such as assignment of materials properties to individual components in the model. The design lab needs its own software for performing IGES translations. Currently, the design teams

rely on assistance from the Mechanical Engineering Department. There is at least one

copy of AutoCAD R13 compatible IGES translator program sign out by the department.

Its location is unknown.

APPENDIX A. HISTORY OF NPS HELICOPTER DESIGN COMPETITION

A.   DESCRIPTION AND HISTORY

Helicopter design education at NPS occurs in the final quarter of a three-quarter

sub-curriculum in the Aeronautical Engineering department. It is a capstone course in

which the two previous quarter's study in helicopter aeromechanics and dynamics are

implemented in a group design project. The class participates in the annual

AHS/Industry/NASA joint sponsored graduate helicopter design competition. The

competition is sponsored in order to promote student interest in the vertical flight

industry. As such, the four current major helicopter companies, Boeing/Vertol,

McDonnell/Douglas, Bell, and Sikorsky, rotate the responsibility of generating an RFP

for which the competing teams formulate a response proposal. Since the RFP is defined

YEAR	PROPOSAL TITLE	PLACE	DESCRIPTION (w/ corporate RFP sponsor)
1993	ARAPAHO	1st	NEXT GENERATION ARMY ATTACK/SCOUT HELICOPTER (MCDONNELL DOUGLAS HELICOPTER SYSTEMS)
1994	PEGASUS	2nd	DUAL MILITARY/CIVIL LARGE CAPACITY VTOL TRANSPORT (BOEING HELICOPTERS DIVISION)
1995	HAKOWI	1st	SEMI-AUTONOMOUS SAR UAV (BELL HELICOPTER TEXTRON)
1996	MONSOON	2nd	VTOL FIREFIGHTING TANKER (SIKORSKY AIRCRAFT CORPORATION)
1997	VIPER	2nd	HIGH SPEED VTOL FIGHTER/ATTACK ESCORT FOR THE V-22 (MCDONNELL DOUGLAS HELICOPTER SYSTEMS)

Table A.1 NPS Helicopter Design Competition History

by industry, its criteria have always challenged students to address vehicle concepts and technologies on the cutting edge of vertical flight.

The competition has been held every year since 1984. The NPS students have entered a proposal every year since 1993, achieving remarkable success. Table A.1 summarizes these proposals. In addition to earning the NPS program notoriety, the design projects have initiated numerous student theses and research projects. The department's main helicopter performance and analysis program, JANRAD, was developed as a tool for the first RFP response in 1993 by MAJ Walter Wirth.

The NPS helicopter design team is the only competitor that completes the entire project in a three-month time frame (April-June). However, these students are uniquely qualified to succeed at this pace based on their backgrounds. Each team member typically has an average of 1500 hours of operational experience flying military helicopters, an environment that places great importance on systems knowledge. With team members from all of the armed forces, the group usually possesses knowledge of helicopters of all of the major manufacturers. Additionally, the military managerial and teamwork experience of the group has been essential to meeting the demanding timeline. Students who begin a preliminary study of the RFP in AA 3272 assist this effort.

The role of the professor in helicopter design has always been purely as an advisor and coach, with students making all decisions and performing all of the analysis. However, the background in industry and the professional knowledge and contacts of the advisor has proven invaluable to the process. Having one professor teaching all of the helicopter track courses has ensured students are prepared for all of the areas of analysis needed for the design project.

Another important role played in the project is the conceptual design review that occurs at approximately four weeks into the quarter. The class has always benefited substantially from the critiques of Dr. Michael Scully, Ph.D. et al. from the Army Aeroflightdynamics Directorate at NASA Ames. Each year, students have given a PowerPoint presentation of the merits of their conceptual configuration and background research performed. The preliminary design department there has generously devoted the better part of a day offering critiques and listing worthy references to pursue.

The milestones for the timeline of the design competition are listed in Table A.2. The events fill an entire year. Although the design effort is accomplished in the single spring quarter, the RFP is released in the fall, allowing students to ponder the subject or compile references if interested.

MILESTONE	DATE
RFP RELEASE	01 OCTOBER
LETTER OF INTENT SUBMISSION	15 APRIL
PROPOSAL SUBMISSION	01 JULY
WINNERS ANNOUNCED	01 SEPTEMBER

Table A.2 Design Competition Timeline

Current rules and RFP requirements [Ref. 14] have been incorporated to focus design efforts on crucial points and "level the playing field" [Ref. 15]. In the 1997 competition each group could have no more than ten participants. The length of the proposal was limited to 100 pages. These requirements facilitate the judging as well.

B. DESCRIPTION OF PAST NPS PROPOSALS

1. ARAPAHO (1993)

The ARAPAHO was designed as a next generation attack and scout helicopter with a 200 kt forward airspeed [Ref. 16].
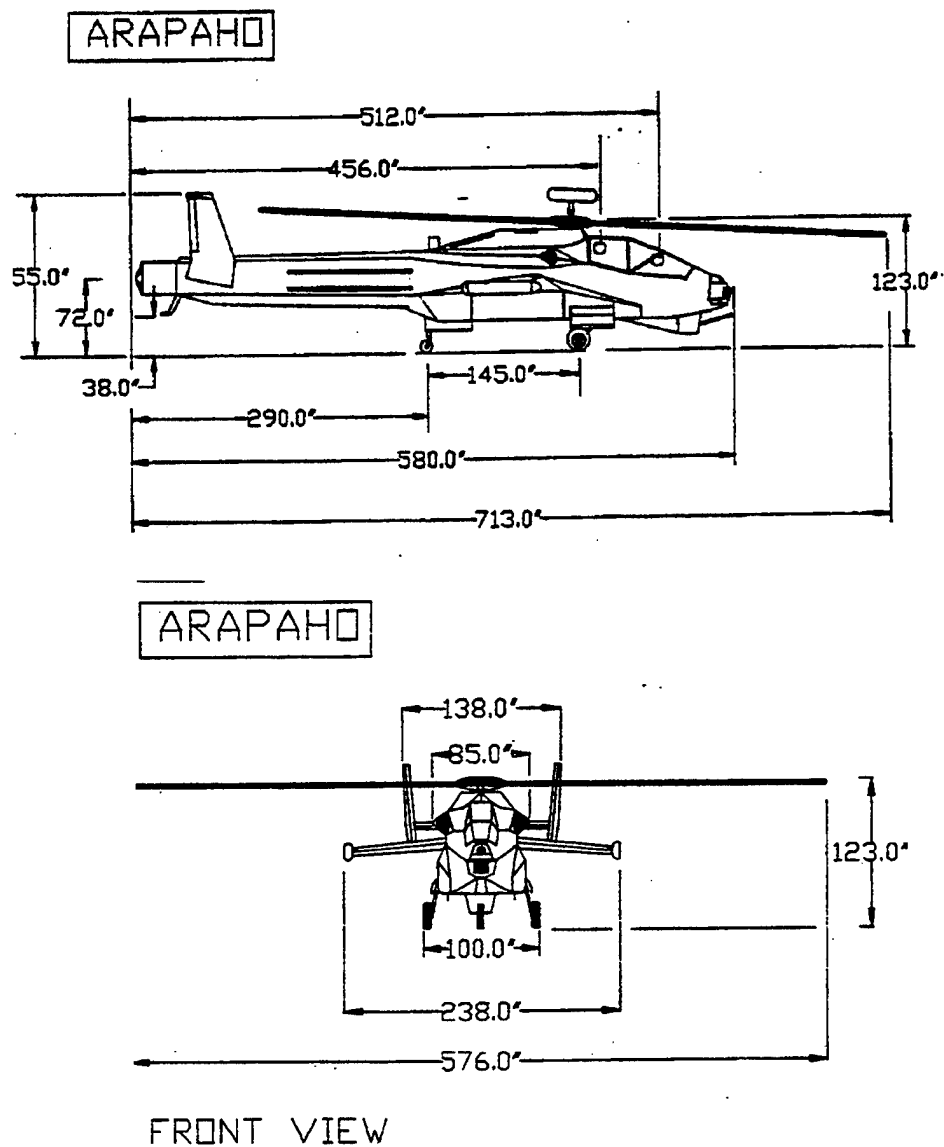
Figure A.1 ARAPAHO Scout/Utility Helicopter [Ref. 16]

2. PEGASUS (1994)

The PEGASUS was designed as a next generation medium lift helicopter for multi-role combat missions. It was designed for shipboard use and all-weather. The designed requirements also called for an aircraft that could be economically adapted for commercial use [Ref. 17].
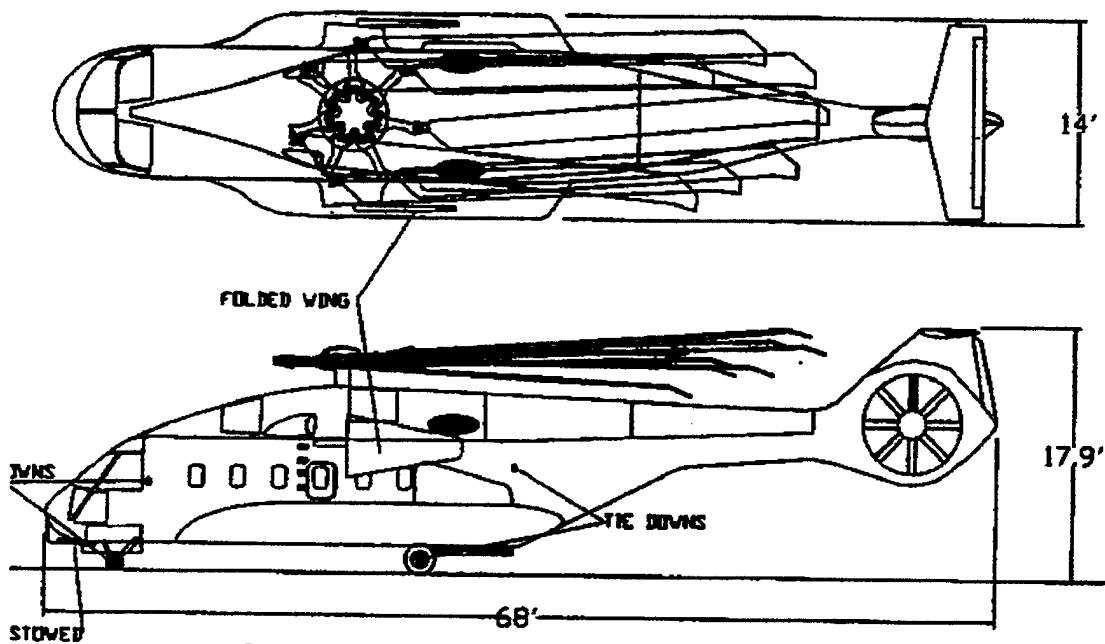
Figure A.2 PEGASUS Military/Civil Large Capacity VTOL [Ref. 17]

3.   HAKOWI (1995)

The HAKOWI was designed an unmanned search and rescue vehicle for

hazardous operations. It was designed for shipboard operations and an all-weather

capability [Ref. 18].
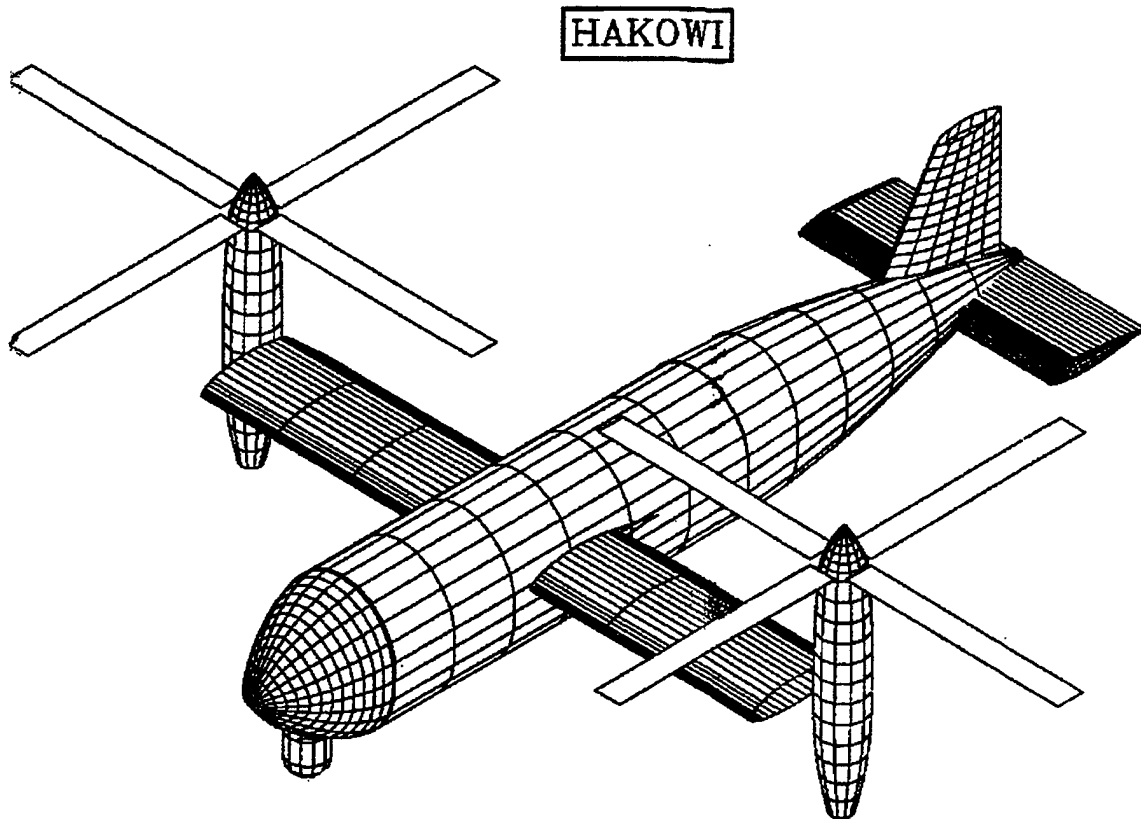
Figure A.3 HAKOWI VTOL SAR UAV tiltrotor [Ref. 18]

4. MONSOON (1996)

The MONSOON was designed as a fire-fighting helicopter with an internal tank and pumping hardware. One of the primary challenges of the project was the mission optimization to achieve the most efficient design to be capable of containing a 200 acre fire in ten hours [Ref. 19].

Figure A.4   MONSOON Firefighting Tanker [Ref. 19]

5. VIPER (1997)

The VIPER was designed to the requirement to serve the role of air-to-ground and air –to-air attack escort for the V-22 OSPREY, as such, it required a 400 knot dash speed, Sidewinder and Maverick Missiles, and a 5-G level turn capability [Ref. 7].

Figure A.5 VIPER Advanced Tactical Tiltrotor

APPENDIX B. LISTING OF NPS AERO DEPARTMENT CAD SOFTWARE

AUTOCAD

A CAD, visualization, modeling and analysis tool. It is available on PC in the design lab.

FLIGHTLAB
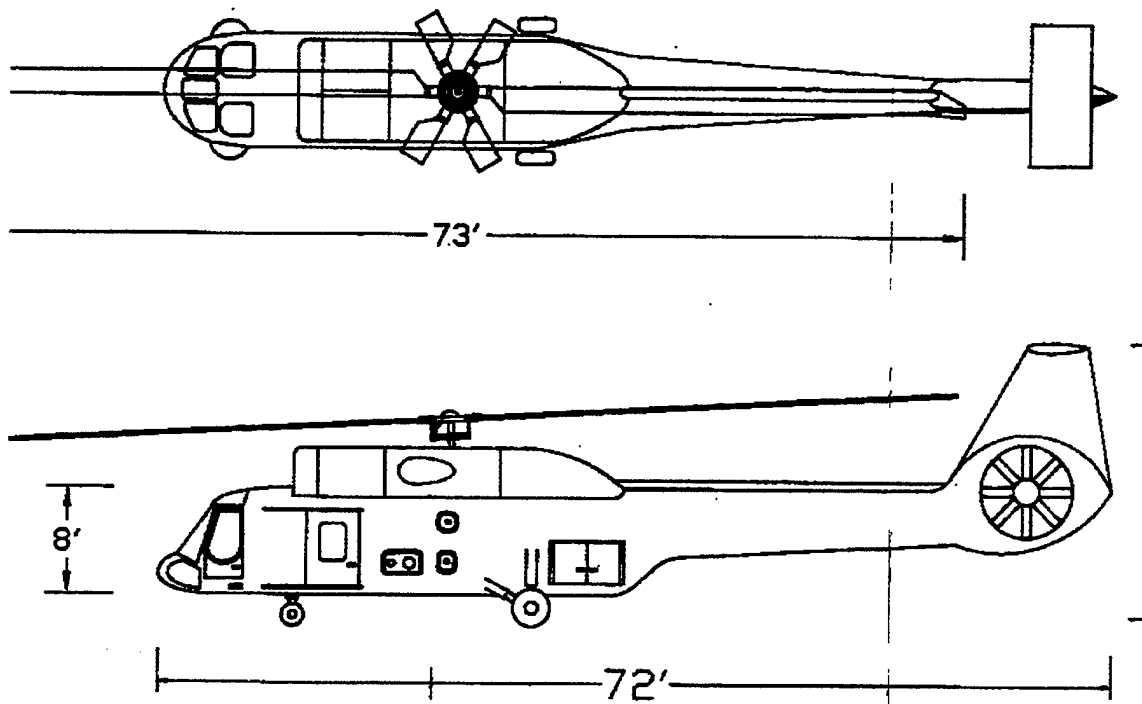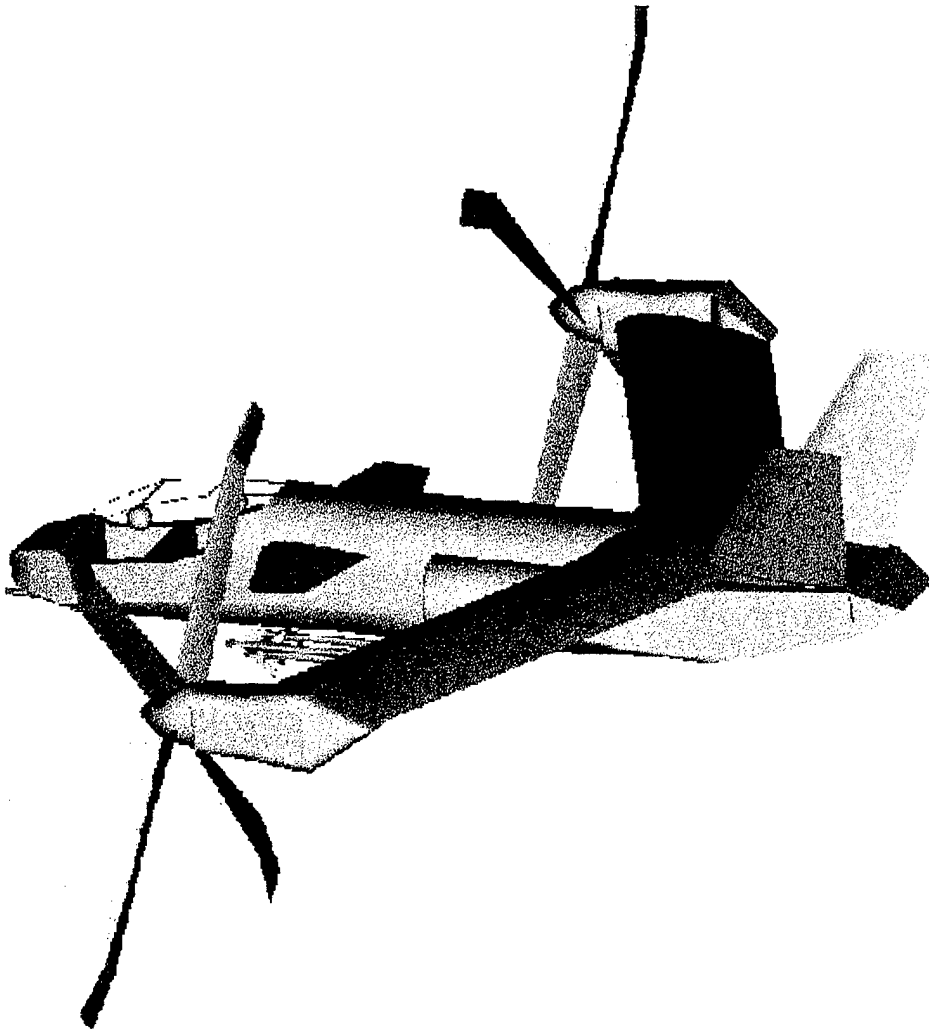
A rotary-wing dynamics and performance modeler and simulation tool. This is available on the UNIX network.

IDEAS

A CAD, visualization , modeling, dynamical analysis, and finite element modeler. It is available on the UNIX system.

JANRAD

An interactive rotary wing performance, dynamics, and parameter identification solver which is written in MATLAB and updated with GUI's for use with MATLAB 5.0. There is also a tiltrotor version designed for the rotor-borne to wing–borne conversion analysis.

MATLAB

A high level language numerical solution software specially designed for matrix manipulation. It is available both on UNIX and on PC in the design lab.

NS3501

A Navier-Stokes Equation solver that computes the pressure distribution and MACH distribution for airfoils through transonic flow. It uses inputs of airspeed and airfoil coordinates. It is available on the UNIX network.

NASTRAN

A finite elements solver that uses PATRAN as its CAD tool and finite element modeler. It is available on UNIX with an access code.

PATRAN

A CAD tool and finite element modeler for structural design. It is available on the UNIX system with an access code.

SIMULINK

A system and dynamics modeling and simulation tool which works in the MATLAB environment. It is available both on UNIX and on PC in the design lab.

UPOT

Unsteady Potential flow solver. This program computers the pressure, lift, and drag coefficients of steady and plunging airfoils for incompressible flow. It is available on UNIX.

LIST OF REFERENCES

1. Layton, D. M. and Kee, S. G., *A Conceptual Design Program for Educational Purposes*, AIAA-83-2473.

2. Lawry, M. H., *IDEAS Master Series 1.0 Student Guide*, SDRC, 1993.

3. Geomtric and Solid Modeling Web Page, University of North Carolina at Chapel Hill, N.C., http//www.cs.edu/~dm/geom.html

4. Autodesk Inc., Mechanical Desktop, web page, http//www.autodesk.com/products/mech/desktop/prodsum.htm.

5. Shoop, B. P., VIPER, p. 41, VIPER, Naval Postgraduate School/American Helicopter Society 1997 Design Competition Proposal.

6. Autodesk Inc., *AutoCAD User's Guide*, Autodesk Inc., 1993.

7. McEwen, M. D. et al, VIPER, Naval Postgraduate School/American Helicopter Society 1997 Design Competition Proposal.

8. Autodesk Inc., Mechanical Desktop, web page, http//www.autodesk.com/index.htlm mechanical desktop

9. McCoy, A. H., p. 16, VIPER, Naval Postgraduate School/American Helicopter Society 1997 Design Competition Proposal.

10. AutoCAD User Group Web Page, http//www.autodesk.com/support/resource/usergrps.htlm.

11. Shoop, B. P., p. 44, VIPER, Naval Postgraduate School/American Helicopter Society 1997 Design Competition Proposal.

12. Laplacik, C. F., VIPER conceptual sketches, AA 4306, Naval Postgraduate School, Feb 1997.

13. Gallello, D., Autodesk Inc., Mechanical Desktop, Web Page, http//www.autodesk.com/ebd/spring97/ebds9707htm

14. AHS International Directory, 1997.

15. Woods, E. R. et al, Minutes, AHS Educational Committee Meeting, 11 May 1994.

16. Et at, ARAPAHO, Naval Postgraduate School/American Helicopter Society 1993 Design Competition Proposal.

17. Hagwood, G. et al, PEGASUS, Naval Postgraduate School/American Helicopter Society 1994 Design Competition Proposal.

18. Sauter, G. et al, HAKOWI, Naval Postgraduate School/American Helicopter Society 1995 Design Competition Proposal.

19. Beaver, W. et al, MONSOON, Naval Postgraduate School/American Helicopter Society 1996 Design Competition Proposal.

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